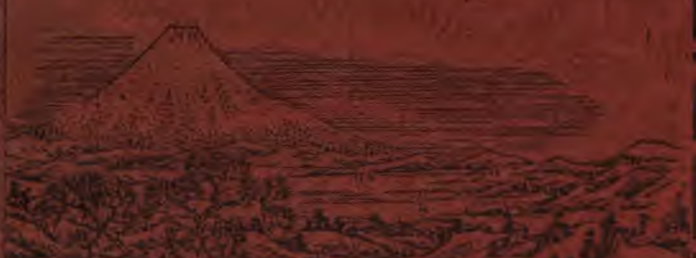
THE

SEISMOLOGICAL JOURNAL OF JAPAN

EDITED BY

JOHN MILNE, F.R.S.



VOL. I. 1893.

Corresponding to Transactions of the Seismological Society
Vol. XVII.

PRINTED AT THE OFFICE OF THE "JAPAN MAIL," YOKOHAMA.

Price Yen 2,50.

TRANSACTIONS

OF THE

SEISMOLOGICAL SOCIETY OF JAPAN.

GENERAL INDEX, VOLS. 1-16.

PRICES. TRANS. SEISMOLOGICAL SOCIETY—JAPAN.

Volume, I	1.50	Volume, IX-2	1.50
Volume, II	0.75	Volume, X	1.50
Volume, III	1.50	Volume, XI	1.25
Volume, IV	1.25	Volume, XII	
Volume, V	1.25	Volume, XIII-1	1.00
Volume, VI	0.50	Volume, XIII-2	1.00
Volume, VII-1	0.50	Volume, XIV	2.00
Volume, VII-2	1.50	Volume, XV	1.50
Volume, VIII	1.00	Volume, XVI	1.50
Volume, IX-1	1.00		

KELLY AND WALSH, LIMITED, Yokohama.

JOHN MILNE, 14, Kaga Yashiki, Tokio.

J. ARNOTT, 67, Birdhurst Rise, Croydon, England.

The prices are in American Dollars payable by draft on any Foreign Bank in Yokohama, or by P.O.O. at the rate of \$0.25= 1 shilling=1 mark.

SEISMOLOGICAL JOURNAL

OF JAPAN.

EDITED BY JOHN MILNE, F.R.S.

VOL. XVII., 1893.

This Journal is a continuation of Publications hitherto issued under the title of the Transactions of the Seismological Society.

PRINTED AT THE OFFICE OF THE "JAPAN MAIL."

CONTENTS.

PREFACE.

THE present volume, rather than being regarded as a new publication, may be looked upon as a continuation of a series of volumes published by the Seismological Society of Japan. This Society was founded in 1880, and for many years its meetings were frequent and well attended. At one exhibition, which extended over several days, the visitors were so numerous that it became necessary to admit them in detachments. Of late years, however, partly in consequence of those who took an active interest in Seismological investigations having left Japan, partly because Geological, Engineering, and other publications accepted materials which formerly found a place in the Transactions of the Seismological Society, and for various other reasons, little by little, interest at last so far flagged that it became difficult even to obtain a quorum sufficient for the transaction of the Society's ordinary business. The result was that in 1892 the Seismological Society ceased to exist.

The work it accomplished is contained in sixteen volumes. Seismographs which led to absolute measurements of earth motions were invented and the whole system of earthquake observation was changed. A chair of Seismology at the Imperial University of Japan, and a Bureau controlling a Central Observatory and some 700 outside Stations, together with many Seismological labo-

ratories, were established. The result, as is testified by recent publications in various languages, and by the types of instruments now employed in many parts of the world, being that earthquake investigations are now conducted on lines very different to those which were followed some thirteen years ago.

As examples of results which have proved themselves to be of immediate utility, may be mentioned the adoption of various contrivances, especially those relating to steady points for the measurement of motions like the vibration of steamships and railway trains, and the practical application of principles enabling us to mitigate the effects of earthquakes upon buildings.

Many investigations remain to be carried out, and although the Seismological Society has ceased its existence, the writer trusts that he may have the assistance of all who are interested in problems relating to earth movements in extending the work which has already yielded such satisfactory results.

JOHN MILNE,
14, Kaga Yashiki, Tokyo,
Japan.

February 20th, 1893.

ON THE MITIGATION OF EARTHQUAKE EFFECTS AND CERTAIN EXPERIMENTS IN EARTH PHYSICS.

By John Milne.

Professor in the Imperial University of Japan.

There seems but little doubt that since the earliest times, all irregular and sudden manifestations of nature's powers, whether by wind, by fire, by water, or by the shaking of the ground, have excited the imagination, given rise to superstitions, and as a result of terror and the terrible effects of great disasters, created a desire to avoid results which might follow their repetition.

As a remarkable illustration of this latter effect, we have the action of the Imperial Government of this country, who being desirous of avoiding a repetition of the disasters following a shaking like that which on October 28th, 1891, devastated the provinces of Mino and Owari, have set aside a sum of 42,000 *yen* to be used as an assistance in making investigations, which while enlarging our knowledge of earthquake phenomena, will make us better able to mitigate their effects.

I do not know the ideas that each member of the Imperial Parliament held when he voted for this expenditure—which, may be supplemented by additional grants in succeeding years—but it is fair to assume that the actuating motive was to avoid, or at least to palliate, the effects of the terrible shakings which from time to time devastate this Empire.

Last year in Central Japan over 4,000 square miles had been tossed into a sea of waves, the country was fissured throughout its length and breadth, forests had slipped like avalanches from

A

mountain sides, valleys had been compressed and the areas of tenements reduced. Allotments of ground had been relatively shifted, whilst engineering structures and buildings throughout the district had been shattered or destroyed.

Official reports tell us that 9,960 people were killed, 19,994 were wounded, 128,750 houses were entirely destroyed, and all other buildings within an area of many thousands of square miles were severely shattered. To sum the matter up, we are well within the mark if we say, that during at least half a minute Japan was suffering a loss at the rate of one million *yen* per second.

There is but little doubt that the picture of this disaster was in the minds of those who acquiesced in the proposal, and that they consider it would be well to prevent, or at least to mitigate, a repetition of such calamities; the nature of the work to be pursued, and the methods to be followed when carrying the same into effect were entrusted to a Committee composed of distinguished engineers, architects, physicists, geologists, and other scientists in this country.

To carry out the task that is now before them in its entirety, is an impossibility. Earthquakes cannot be prevented; and so long as they continue, from time to time buildings must suffer damage. There is, however, not the slightest doubt that by attention to the result of experience in this and other countries, and by taking advantages of the knowledge gained from experiments on earth motion, more particularly those which have been carried out in this country, so much may be done in the modification of various structures that it will practically be an impossibility to have a repetition of a disaster so extensive as that which recently took place in Mino and Owari.

So long as we neglect the results of these experiences and experiments, we may expect—nay we even invite—a repetition of those calamities, and at any moment thousands of lives may again be lost and in a few seconds the country may once more be compelled to meet a forced expenditure of many millions.

Rules, which, if carried iuto effect will most certainly mitigate these natural calamities, have already been formulated in many earthquake countries, and, with the reasons which have led to their adoption, are to be found.in Vol. XIV. of the Transactions of the Seismological Society of Japan. To bring these, or their modified form, into force, would no doubt be a proceeding extending over many years.

During this time, certain special investigations, relating to the stability of walls, and the nature of certain hitherto neglected peculiarities in earthquake motion, ought to be made. Further, we might even go so far as to see whether it is not possible to forewarn ourselves against the coming of these dangers. Up to the present all our endeavours to foretell the occurrence of earthquakes have failed, and we are without means of definitely stating when and where an earthquake may be expected. Although the prediction of these fitful workings, from all that has hitherto been done, seems to be almost an impossibility, there yet remain investigations which should be made, before we relinquish what appears to be an impossible task, and in the following summary of what may be done to palliate the effects of earthquakes, one of them is indicated.

1.—Construction.

Some years ago, at the suggestion of His Excellency the late Mori Arinori, a Committee was summoned to consider Construction in Earthquake Countries, and as a contribution to the work, the writer with the cōoperation of his friends, communicated with all earthquake countries in the world, and obtained from them rules and regulations respecting building, which had been enforced with the object of minimizing the effects of earthquakes. These, together with plans, drawings, opinions, the deductions to be drawn from the author's observations in Italy, Manila, and Japan, and also the results of many special experiments bearing upon construction, were embodied and summarized in Vol. XIV of the Transactions of the Seismological Society. These have been criticized by engi-

neers in Japan, and in two papers read before the Institute of Civil Engineers in London, they were commented upon at considerable length by many who had been engaged in construction in South America and other earthquake countries. Taking this work as it now stands, it is the writer's opinion that it contains sufficient material to form a basis for rules with which all buildings of a foreign type erected in the earthquake districts of Japan should comply. It also contains much that may be taken advantage of, in the carrying out of engineering works, as for example in connection with railway work, and very much more that is capable of application in the ordinary Japanese dwellings. To extend the usefulness of the latter, it is necessary for architects and builders working in conjunction, to determine how far the principles applied in a foreign earthquake-proof building, can be applied to a Japanese house without altering its form or increasing its cost. Can greater stability be obtained by diagonal bracing, by the introduction of angle iron at joints, without such an extravagant cutting away of material as is at present practiced, and by using a lighter roof, &c.? It is evident that that much can be done, but to accomplish it in a manner tending to minimize the difficulties of its adoption, consultations will have to be held with the ordinary builder, the house carpenter, the blacksmith, and the manufacturers of tiles and other roofing materials, whilst disputed points must be subjected to experiment.

Types of buildings, having in this way been decided upon, models, drawings, and descriptive pamphlets of the same should be issued to all districts where earthquakes are frequent. At important places full-sized buildings which may be utilized for government purposes, schools, and the like, may be erected as required.

This latter course would not only give actual examples of what was required, but it would give local builders an opportunity of fully realizing that which was required by others.

Of next importance come the engineering structures like

bridges, dykes, reservoirs, tall chimneys, &c. Up to the present almost everything has been carried out on the lines of European practice, and that this has failed, has been fully testified by the results of the last great earthquake. For example, it is doubtful if a pier to carry a bridge has ever—either in this country or any other—been designed with a view, not only of carrying the superincumbent load, but of resisting more or less horizontally applied stresses due to its own inertia.

A common wall put together with a mixture of lime and water, although perfectly stable, so far as its weight is concerned, is utterly valueless against horizontally applied forces.

Reasoning and experiments show us that these structures should have horizontal sections the strength of which decreases with the height, while the strength and adhesivity of the cementing material ought to approach that of the masonry.

To carry these and other principles into force will require engineers to consider the results of their past experiences, the results of experiment and reasoning, to carry out new investigations, and finally to draw up rules to be followed for construction in the future.

2.—Rules and Regulations.

Taking the material already in our possession, especially that relating to buildings of a foreign type, it seems desirable that a summary of the same should be presented to the Imperial Parliament for their consideration, with the object of subsequent legislation on these matters.

At the present time, in Tokyo and all large cities, buildings of a foreign type are springing up with alarming rapidity, and the more they are allowed to increase, the greater will be the disaster when they fall, and this, many of them will most certainly do on the occurrence of an earthquake of moderate severity.

In connection with these laws, there are several points

of importance which have escaped the attention of legislators in other countries; for example: it would be well to specify a definite strength to be given to mortar or cement joints—it would appear to be advisable to make the regulations more rigorous for buildings in dangerous situations, as for example along a river bank, &c.

3.—Experiments to increase our Knowledge of the Nature of Earthquake Motion.

In consequence of work which was carried out in Japan, and in Japan only, we have now absolute measures of earthquake motion as received at any particular point. We know the distance through which a point moves back and forth, and we know the rapidity with which these motions are performed. These quantities are no longer matters of opinion or deductions from hypotheses, but they are recorded as absolute measures which can be used by the engineer when constructing to withstand the forces they represent. For example: he can say that the results of observation do not show that a building is likely to receive a shock greater than that it would experience if it were placed on a truck which commences to move with a velocity of 10 feet per second, and therefore rather than making a building strong, because an earthquake is strong, he can construct to withstand the effects due to a measurable force. Further, the results of experiments have shown him the form and strength required in different portions of his structure. Again, experiments have shown that the motion 10 or 20 feet below the surface is less than it is on the surface itself. Advantage has been taken of this discovery in the erection of several important buildings in Tokyo, which rise from a basement, instead of, as in ordinary practice, from the surface. In this and other ways, have scientific enquiries respecting earthquake motion resulted in knowledge which has received an immediate practical application. Much more, however, has yet to be learned before we can state with confidence that our knowledge of earthquake motion is approximately perfect.

For example :—it is desirable to know the length of earthquake waves, of which there are at least two kinds, waves which may be compared to those of sound and those which are more like those we observe in water. In neither case have we waves which are altogether truly elastic, or waves which are entirely due to gravity, but we have waves embodying both of these characters, the exact nature of which will vary with the character of the initial disturbance, their proximity to their origin, and with the nature of the medium through which they are propagated.

To measure the former—which, like the latter, probably vary in length as they are propagated through a varying medium—we require more definite knowledge respecting the velocity with which earthquake motion is propagated. The latter, which are noticeable at the time of large earthquakes, and when vertical motion is pronounced, may be measured either in a similar manner, or by specially designed instruments, which give not only the period of their movements but also record their varying slope.

In the latter case, in order to define the dimensions, as well as the form of the passing waves, in addition to the information respecting period and change of form, we need records of the vertical displacement. As ordinary seismographs for vertical motion may be affected by changes in inclination, a special form of seismograph, which will at least give an approximation to the true vertical motion, has been constructed.

As has often been pointed out before, both in discussions and in print, we see that our present seismographs are of but little value as measurers of earthquake motion, whenever a vertical component is strongly defined. At a distance from an origin, near the end of a disturbance when the earth waves are *slow*, and on a plain like that of Tokyo, we have many reasons for believing that they are symmetrical in form. For waves of this type the ordinary bracket seismograph has been used for measuring their angular configuration, and thus approximate dimensions have been calculated.

An instrument more generally useful would probably be a *quick vibrator*, which has small inertia, and, is in its action, *dead-beat.* The records of such an instrument taken on a *quickly moving surface*, would give us information respecting angular configuration; and this, in conjunction with a knowledge of period and vertical displacement, would enable us to define the form and dimensions.[1] We have evidently here a new field for experiment and observation, the results of which will extend our knowledge of the exact character of earthquake motion.

As another example of the problems which are yet unsolved is the determination of the extent to which two neighbouring points of ground accord in their movements. The practical application of information of this character is obvious, for it is evident that if we are assured that a piece of ground carrying a building moves similarly and simultaneously in all its parts, the construction of such a building may be different to one which is being racked by one portion of it moving in one direction whilst another part is moving in another.

Another direction in which seismological investigations may be pushed, is the determination of the relative intensities of earthquake motion as felt at a number of neighbouring stations. Some years ago a fairly accurate seismic survey was made of the compound of the Engineering College at Tora-no-mon, when it was shown that on a piece of ground only a few acres in extent, the motion experienced on one part of it was invariably very much greater than it was on other parts. In other words, the movements were so different on the two sides of the compound, that a building on one side of it might be shattered, whilst a similar building on the opposite side might remain undisturbed. Investigations of this description need amplification.

[1] An instrument designed and put up by the author intended to measure angular displacements, consists of two similar parts placed at right angles—each part being a beam loaded at either end and carried on knife edges at its centre, as in an ordinary balance. The portion corresponding to the pointer of a balance, moves a horizontally placed multiplying lever, one end of which records its motion on a moving smoked plate.

4.—An Extension of the Functions of the Earthquake Bureau now established at the Chuwo Kishodai (Chirikioku).

Since 1882, the Chirikioku has been in correspondence with some 700 observers who are fairly evenly distributed throughout the empire. When any of these observers feel an earthquake, an account of the same, together with such instrumental records as they may have, are forwarded to the Central Observatory. Based on these records, a map is drawn showing the area shaken by each earthquake, and information relating to its direction, intensity, and other things are recorded. At the end of each year a summary of these records is made, and the area of the land shaken per month, the times when earthquakes were most frequent, &c., are given in forms which are usually tabular. The work that is done is good, and it has undoubtedly already yielded results of great importance to the student of earth physics. It is, however, certain that this department desires the means of extending its usefulness, and it is to be regretted that material means to carry on analyses of the rapidly accumulating records, which are without parallel in other parts of the world, are at present wanting. For example: it is desirable in addition to examining the records as a whole, to analyse the records of earthquakes from particular origins separately, to devote particular attention to particularly sensitive areas, which from time to time show themselves, first in one part of the empire and then in another. For example: many months before the occurrence of the great calamity in Mino and Owari, it seems from the records, that small earthquakes were unusually frequent to the north of Gifu. Possibly these may have been minor yieldings in the rocky crust, which heralded the final crash which devasted the surrounding district. By more extended investigation of the material already accumulated, by special investigation in the districts where disturbances suddenly become unusually frequent, and in many other ways, it seems that there might be a useful extension of the present functions of the Chirikioku.

5.—Prediction of Earthquakes and measuring Secular Movements of the Earth's Crust.

If we were able to predict the occurrence of earthquakes, we should at least have the opportunity of partially avoiding their more serious effects.

Earthquake prophets have been numerous, some basing their predictions on peculiar instincts, others on supposed peculiarities in atmospheric conditions, others on calculations respecting the movements of subterranean tides, which, entering cavities and fissures in the weaker lines of the earth's crust cause sudden yieldings.

The predictions having been numerous, as a result of the laws of chance, it has occasionally happened that they have been fulfilled. In the majority of instances they have failed. At one time, many thought that the frequency of the minute movements called earth-tremors, might indicate the coming of an earthquake, much in the same way that the cracking of a bending stick announces the fact that the limits of elasticity are being passed and it is about to break. Careful investigations in Japan, however, have shown that these movements are unconnected with earthquakes, and are more likely to be the results of stresses due to varying barometric pressures exerted over areas of considerable extent.

The only way in which we are likely to be able to predict earthquakes which suggests itself to the writer, is to determine whether they are preceded by or are in any way related to slow changes of level in the earth's crust.

The hypothesis is, that earthquakes are the result of faulting, and that faulting is due to a bending of the earth's crust beyond its limits of elasticity.

The principal reasons for this hypothesis are:—

1. Even in volcanic countries, the majority of the earthquakes which are recorded do not appear to be in any way connected with volcanic action. Before a volcano commences

to erupt, there may be a few slight shakings of the ground, and there is certainly another small disturbance at the time of the final effort, when the rocky material above the crater mouth is burst asunder. These occurrences are, however, rare, whilst earthquakes, many of which are large, are of continual occurrence, and whether a volcano is at rest or in a state of activity, these disturbances do not appear to be in any way affected.

2. Earthquakes are frequent where we have evidence of secular movements of the earth's crust; as for example, of coast elevation, or where mountain formation is possibly still in progress. Along the Eastern Coast of Japan the borings of marine shells in a soft tuff rock give evidence of recent elevation. Near Yokohama, the average rate at which the coast appears to be rising is, perhaps, a quarter of an inch per year. Evidences of secular movements are common in most volcanic districts where earthquakes are frequent. Again, earthquakes occur in non-volcanic districts like Switzerland and the Himalayas where mountains are geologically young, and where it is likely that the crumpling of the earth's crust is yet in progress. The earthquake in Mino and Owari was in a non-volcanic district, and it was accompanied by, and in all probability is the immediate result of the formation of a large fault and many minor ones which are now visible on the surface.

3. After nearly all great disturbances we have a long series of smaller shocks, indicating the formation of minor faults, and a gradual sinking of the disturbed strata to a state of rest. On the faces of cliffs and other places where faults are exposed in section, it is a common observation that large displacements are flanked by many minor displacements. These were probably formed after the formation of the primary fracture, and represent the intermittent settlement of disjointed strata.

Assuming then that the majority of earthquakes are interruptions in the general process of elevation, a water level, if of sufficient length, placed at right angles to an axis of elevation,

might possibly show fluctuations which would measure this process.

Assume the level to be made of 1½ inch gas pipe about two *ri* (5 miles) in length, laid like ordinary water pipes but terminated at each end by a vertical standard of glass tubing resting on well constructed masonry foundations, then, if any change in the general slope of the country across which the pipes were laid took place, it would cause the water to fall in the one standard, by an amount equal to the height it would rise in the other. Leakage (which, however, might be compensated for by a supply tank connected with the line) would show itself by an equal amount of fall in each of the standards. Records of the level of the water in the standards relative to their foundations, might from time to time be made by direct observation, or continuously by means of photographic apparatus.

As it might be difficult to instal such an arrangement as is here proposed exactly at right angles to an axis of elevation, two lines of pipes at right angles to each other in any azimuths would be required. One line of water pipes placed parallel to an axis of elevation could not be expected to show any changes.

Among the chief results that might possibly be reached by this experiment, would be the determination whether secular changes of level, in quantities sufficiently well defined and rapidly performed to be measurable by this class of apparatus have an existence, and if they exist whether they are in any way connected with the occurrence of earthquakes.

In addition to these, the observations could hardly fail to throw light upon the tilting of columns carrying astronomical instruments, possible changes in the height of observatories, and other important changes relative to sea level, the rate at which harbours may be shallowing, the existence of earth pulsatons, and other phenomena connected with the earth's crust, which have hitherto been outside the range of measurement.

As a check upon these experiments, at intervals of say a year, the difference in height between the two foundations might be determined by ordinary leveling.

As a guide to determine where elevation is most pronounced, and therefore where investigations respecting secular changes may be best observed, the writer suggests that by means of circulars sent to each town and village on the coast, information could be obtained from the old residents as to whether such changes have been observed, or whether there are traditions respecting alterations in the level of the water relatively to the land.[1]

At certain places, permanent rocks might be marked, as was done by the Swedish Government, and the distance between these marks and the average sea level recorded.

As the latter quantity is subject to considerable fluctuations, we can only hope to determine the existence or non-existence of elevation by this method of observation, after long intervals of time.

The writer has suggested that the *relative* elevation of two or more points may be more quickly determined by observing the difference in the records obtained at the same time from two or more tide gauges situated round the shores of a bay where the rise and fall of the tide is not excessive.

If there is no change taking place between sea level relatively to the land, then these differences between the heights measured at the various stations, which heights are measured relatively to certain bench marks at those stations, should when the tide is in the same phase and there are no distrubances, as for example, due to the piling up of the water by the wind, remain constant. The chief assumption here made is that during similar phases of the tide, the surface of the water has the same configuration. By means of a system of stations in

[1] With the kind assistance of Prof. D. Kikuchi these enquiries are now being made.

nearly a straight line, the configuration of the water surface under varying conditions along that line, might be determined. As an illustration of how the work might be systematically performed we will assume that we have at least these tide-guages, each from 10 to 20 miles apart, installed round the shores of Tokyo Bay. With this installation on a series of consecutive days, we can readily determine the following particulars:—

1. Total rise of water from low water to high water.
2. Whether the tide is increasing or diminishing from day to day.
3. Whether at any point in the vicinity of the mouth of the bay there is no tide.

We can then for one or all of these days determine the height of certain bench marks relative to high or low water (these being convenient phases of the tide) or the height at each of the stations above water level at the same time.

Again, say a year afterwards, let us make similar observations when the tide has the same total rise and is increasing or diminishing as in the previous year. Also it will be necessary to determine whether the point of no-tide has remained fixed, and if not, re-determine the water configuration. Then the difference of the differences between the indications in this case at the several stations and those of the previous case, will measure the relative rise or fall.

Any difference in the height at any one station is an indication of total rise. It is evident that in order to measure these changes and to determine the axis of the movements it is necessary to make observations at at least three stations.

In reply to the query as to the amount of change we expect to measure, we may say that the evidences of elevation round the Bay of Tokyo are sufficient to lead us to expect changes at least equal to that which, for example, has been determined on the coast of Italy.

For example :—the temple of Serapis, near to Naples, since its construction, which was antecedent to the Christian era,—prior to the close of the fifteenth century was submerged at least 20 feet, since which time it has risen 23 feet; and since the commencement of this century it has again been sinking. The rate of subsidence has been determined at various times, being from ¼ to 1 inch annually.

Movements of this character are not local, and what is more, they are common to many parts of the world, especially in volcanic districts. In the district near to Vesuvius, during periods of volcanic activity, subsidence appears to have been taking place, whilst when the volcanoes were dormant elevation was in progress.

6.—Observations on Faults.

On the faces of the cliffs surounding the Bay of Tokyo, very many well defined faults, having throws of from a few inches up to twenty feet or more, which might be studied.

Although the rocks on either side of these lines of fracture have settled to a state of rest, yet the fact must not be overlooked that they represent lines of weakness, along which, should local disturbances occur, further yielding might possibly take place. For example :—Owing to a process of general elevation, or at the time of a severe shaking, a gradual or sudden movement might occur. If the throws of several faults—selecting for example several which were near to the stations for tide observations—were measured, any alteration in their measurements would indicate local subsidence, which, although, probably showing a connection with earthquakes, must not be confounded with the more general movements extending over considerable areas.

7.—Rigidity of the Earth's Crust.

As has been suggested to the writer by Lord Kelvin, accurate determination of the velocity with which vibrations are propagated through the earth's crust, would lead to a

determination of a certain constant often required by physicists engaged in speculation respecting distortion of the earth's crust due to external attractive influence. Already one or two determinations have been made of the rate at which earthquake motion has been propagated between Japan and Europe, but before these can be applied to the determination of elastic constants, it is necessary that they be repeated with greater accuracy. The best observations of this nature are perhaps those which were made at the time of the great Charleston earthquake, when velocities for the propagation of earth waves reached 5,200 meters per second. As an attempt to measure the bending of a mass of rock as it occurs in nature, some years ago the writer endeavoured to determine whether the roof of the workings in the Takashima Colliery, which extend some distance beneath the bed of the Pacific Ocean, was in any manner disturbed by the rising and falling of the tide. Instruments were prepared and forwarded to Nagasaki, but owing to the death of Mr. John Stoddart, who had kindly undertaken to make the necessary observation, nothing was accomplished.

8.—Experiments in Boreholes.

Many years ago a borehole was sunk in the compound of the Kobu-dai-gakko, to the depth of 100 feet, and at depths of 25, 50, 75, and 100 feet respectively, thermo-electric junctions were established, which enabled the temperature at those depths to be measured at any moment. Boreholes, in which earth temperatures have been measured and heat gradients determined, exist in many countries.

In Germany we find seven holes each exceeding 3,000 feet, and one of them at Schladebach, over 5,700 feet in depth. In the oil regions of the United States we have yearly about 1,000 holes, sunk to depths varying between 1,000 and 3,000 feet.

From observations in these holes, mines, tunnels, &c., an average heat gradient has been obtained, and anything that

can be done by sinking a deep bore-hole in Japan, is not likely to add to our present knowledge more than what may be of local interest. A heat gradient, which we have no reason to believe is likely to show fluctuations, can be obtained for the rocks beneath a certain locality, and it will not be exactly the same as any other heat gradient.

Geologically and commercially, a deep bore-hole, carried out in Tokyo for example, may lead to results of considerable value.

It will yield information to the Geological Survey, a bad quality of coal, or hot water may be met with. Even if only pure water is obtained, such a result may be of value in a city not yet possessing a proper water supply. We do not, however, see that it is likely to throw new light upon seismic or volcanic observation, the depth to which it may penetrate being so insignificant compared with the depth at which we may expect volcanic or seismic forces to have their origin.

Although but little may be learned respecting the organization of our mammoth by gently puncturing its skin, we must not forget that boreholes have hitherto only been utilized by physicists, as a means for determining heat gradients, and we may ask ourselves the question whether they may not be employed as a means for making other investigations. For example :—Earth currents are studied as phenomena resultant in differences in potential between points on the surface of the earth. With a borehole at our disposal, may we not determine whether these forces have a vertical component?

9.—Variations in Latitude.

For many years it has been suspected, and now it is known, that we are sometimes from 50 to 100 feet nearer to the pole than at other times. For example: at Berlin at the commencement of 1890 the latitude was 52°.30′.17″. In the middle of September it had gradually reached 52°.30′.17″.56. By February, 1891 it had returned to 52°.30′.17″.06 and in June and July of that year it had risen to 52°.30′.17″.53.

It is certainly remarkable that the period of maxima increase in latitude in Berlin (which may correspond with a minima in values for latitude in Japan) should coincide with a maxima of earthquake as recorded in Japan, that is in August and September, 1889, and in May and June, 1890. Until further observations are made the writer is, however, inclined to regard these coincidences as accidental.

10.—Observations on Gravity.

When a pendulum is repeatedly swung at a given station, as might be expected, there is not an absolute agreement between the results leading to the calculation of the acceleration due to the force of gravity. A question which presents itself is whether these slight differences are the result of instrumental and personal errors in observation, or whether it is possible to trace them to some more general influence. For example:—It seems probable that when observations are made at the time of a tremor-storm we have earth movements of a pulsatory nature which might either accelerate or retard the swinging of a pendulum. The writer finds that at the times when tromometic disturbances are pronounced, delicate balances are seriously disturbed. To swing a pendulum at an observatory daily for a year, would certainly be an experiment, the result of which would be regarded with interest.

The abnormal results of pendulum observations, made in the vicinity of mountain ranges, have led physicists to speculate as to the nature of the foundation of these ranges. Will observations as to the value of gravity—made for example on the flanks of Asamayama—show us anything respecting the roots of our volcanoes' internal changes which follow or precede great eruptions or seismic disturbances?

11.—Magnetic and Electric Phenomena.

Although Prof. Tanakadate has shown that after the Nagoya-

Gifu earthquake—which was accompanied by a permanent displacement of rocky strata—an exceedingly slight change is observable in the isomagnetic curves, it does not seem likely that either magnetic or electric phenomena will be the means of forewarning us of the coming of earthquakes.

No doubt much that is of interest may be accomplished by making special magnetic investigations near great lines of faults, and on the flanks of our volcanoes, and for various reasons we may expect changes in the magnetic elements to be observable before and subsequent to eruptions.

It must be remembered that, although so much has been written to show that there is a connection between magnetic and seismic phenomena, that magnetic instruments established in Tokyo, although they are repeatedly shaken by earthquakes, have never yet shown any change other than that which might be produced mechanically. Similarly, much has been adduced to show a relationship between earthquakes and electrical phenomena like earth currents and sudden changes in the potential of the atmosphere relatively to the earth but although many attempts have been made to observe such phenomona, no definite conclusions have yet been reached. (See Earthquakes in connection with Electric and Magnetic Phenemena: Transactions of the Seismological Society, Vol. XV. p. 163.)

ON THE APPLICATION OF PHOTOGRAPHY TO SEISMOLOGY AND VOLCANIC PHENOMENA.

By Prof. W. K. Burton.

There is scarcely a branch of art or science that does not at the present day call in the aid of photography, either directly or indirectly, and Seismology is no exception. It may, therefore, not be out of place in the case of a journal particularly devoted to this subject, to enumerate and briefly describe the various applications of photography that have actually been made, or that are suggested, in connection with earthquake and volcanic phenomena.

First, of course, we have the common application of photography to record the effects of earthquakes and of volcanic eruptions. The value of photographs of this kind cannot be over-estimated, but it will not be fully appreciated till considerable time has elapsed, and until future Seismologists want to compare the effects of earthquakes and eruptions of their time with those of the present time. We can imagine of what value they will become if we think what we would give for an accurate set of photographs of the effects of any historical earthquake or eruption, say of the last century. Undoubtedly, a hundred or two of years hence, it will be of the greatest importance to geologists to be able to compare the condition, for example, of Bandai-san with its condition within a few days of the eruption, that blew its upper half into the air nearly five years ago. The more rapid changes in the interior of the craters of

active volcanoes can also thus be noted with advantage. Even such secular movements as the gradual rising or depression of coasts may also, perhaps, be recorded more definitely than they have been heretofore.

There is one thing that should be emphasized here, and that is the importance of preserving systematically all photographs of the kind mentioned, printed by some permanent process. In cases where the photograph is of such general interest that the outside public may be looked upon for the purchase of anything over about 50 copies, the collotype process is at the time of writing to be recommended, in other cases the platinotype, in spite of its present comparative expensiveness on account of the recent great rise in the price of platinum. Up to the present time, so far as the writer knows, such photographs as are of particular seismic interest are to be found scattered through various publications, but have not been systematically brought together in any single collection.

Prof. John Milne has used photography in determining the curvature of the sides of volcanoes.

That is to say the inclination and curvature were measured from photographs at the time in existence. In using photographs for this purpose it is necessary to be sure that the swing back of the camera was vertical at the time the photograph was taken, otherwise the measurements will not accord with the truth. Now, although photographers have been pretty well drilled into appreciating the necessity of having the swing back of the camera vertical in the case of buildings, there are few that appreciate the necessity in cases where the subject contains no right lines, and the greater number of photographers "tip" the camera without bringing the swing back to the vertical again, in photographing a high mountain. This is, indeed, one of the reasons for the commonly unsatisfactory rendering of mountains by photography. The effect of tipping back the camera, without readjusting the swing back, is to

give an effect in the photograph, as if the mountain were leaning away from the camera to just the amount that the ground glass leans back. In other words the slope of the mountain is reduced, and the mountain is dwarfed. There may also be slight errors due to refraction.

We next come to another set of uses of photography that need little more than enumeration. Thus the record of an earthquake, by nearly every seismograph, is scratched on smoked glass, the smoke film being afterwards fixed with common photographic varnish. It goes without saying that photography is the best way of obtaining copies of such records. The blue process is most commonly used, although, in the case of the small diagrams given by bracket and duplex pendulum seismographs, more delicate processes have a decided advantage. Except for want of permanency, albuminized paper is to be preferred to anything else.

It scarcely needs to be stated that photography has been useful in producing illustrations of seismological instruments, also, in a number of matters of detail such, for example, as the production of scales, with finer division than any that were readily procurable machine divided.

We now come to a consideration of more special adaptations of photography to seismology, and, to avoid the necessity for repeating his name every few lines, I state here that nearly all these adaptations are the work of Prof. John Milne F.R.S., the writer sometimes giving assistance in some of the purely optical and photographic parts.

Some two years or so ago, an attempt was made to find whether any change in electrical potential between the earth and the atmosphere preceeded, accompanied, or followed earthquakes. An instrument to keep a continuous potential record was devised on the following lines. One terminal of a mirror galvanometer was connected with a metal plate in a well of considerable depth, the assumption being

that the potential of the well water would be the same as that of the earth at the same depth. The other terminal was carried to a metal plate at the ground level. A beam of light was thrown on the galvanometer mirror and, being reflected, was received on a photographic plate, narrow and long. kept moving slowly in the direction of its length by clockwork, A continually changing potential was shown, and there were several cases in which there were decided deflections at the times of earthquakes, but there was not sufficient consistency in these to make it evident that they were the result of anything but the mechanical effect of the shocks on the galvanometer. The subject is one that yet requires attention.

There has been much investigation of "earth tremors" and "earth tilting." We are accustomed to look on the "solid earth," apart from its planetary motions, as the very type of what is stable and steady, but it is now known that it is never at rest. It is always trembling, and there is reason to believe that its surface is often slowly tilting in one direction or in another. These motions are extremely small; to get indications of them, much less to measure them, is very difficult, and, up to the present, it has been impossible to separate them, one from the other, with certainty. Thus no tremor recorder has yet been made of which it can be said with *certainty*, whether it is recording true tremors or "tips." An ordinary pendulum will be affected by "tilts" but not by tremors, unless these happen to coincide with its period. The difficulty is to record in any way the extremely small motion of the bob of the pendulum. A partly successful attempt was made to solve the difficulty by photography. A silver bead was suspended by a silk fibre in a hollow stone column, which prevented atmospheric influence. A beam of light was thrown on the bead, and the image of the point of light, passing through a micro-objective, placed vertically below the bead, gave an image of the spot of light on a plane at a considerable distance below it, along which a photographic plate could be made to travel

by clock work, the motion of the bead being, of course, greatly multiplied,—being in fact multiplied in the ratio of the distance between the bead and optical centre of the lens* and the distance between the optical centre* of the lens and the plate receiving the image.

A word or two should be said on the optical principles here involved. If a silver bead were a perfect sphere, or indeed, if the surface were everywhere convex, the form only approximating to a sphere, the spot of light produced by the reflection of any source of light, say a lamp flame, could be made as small as might be desired, without being reduced in brightness. The further the source of light is moved away from such a bead, the smaller becomes the spot, but its brightness remains the same and is, indeed, at all distances, leaving air absorbtion out of the question, the same as the source of light itself, less a constant percentage of loss on account of absorbsion of light at the reflecting surface. This arrangement is, in fact, the "artificial star" used by opticians in testing telescopic and other objectives, when it is not convenient or possible to focus on an actual star.

It was thought that, in the case of this instrument, as the spot of light could be made indefinitely small, at will, the image of the spot could be made as small as might be desired, however great the amplification. It was found, in practice, that this was not the case. If the amplification were great enough to be useful, the spot of light was too large to draw anything but a very wide line. The lens was a high class ¼ inch micro-objective, and the fault was probably not in it. It is likely that the bead was not really convex throughout, but that the surface consisted of minute facets, or more likely grooves. If a bead of mercury could by any means be used the results would probably be much better.

Excellent results have been got by the aid of photography

* More strictly one of the "principal points" of the lens.

by the tremor recorder described in a report on the Volcanic Phenomena of Japan. (British Association Reports 1892.)

The only difficulty here is that it cannot be known for certain, whether these instruments are showing tremors or "tips." In this case the light passing through a narrow vertical slit, behind which there is placed a small lamp, passes farther through an objective, is received on the mirror, and is from it reflected on to a horizontal slit in the front of a box which contains a photographic plate moving vertically by clockwork. Of course any motion of the mirror of the instrument, whether produced by tremors or "tips" is amplified by the beam of light, whilst the horizontal slit cuts off all superfluous light, so that a spot only reaches the plate. Daily observations were taken on plates 12 inches long. 2½ inches broad, moved by clockwork, at such a rate that they took 24 hours to travel their whole length. With this slow travelling vibrations were not separately registered. The breadth of the line across the plate, indicated the amplitude of the vibration at any particular time and showed that there attained a maximum at intervals five to ten minutes. In working with these slowspeeds it was found that the light of a small kerosene lamp was ample, if the plates were rapid, but it was considered advisable to get a record of the actual separate vibrations during "tremor storms." To do this the plate was caused to travel rapidly, at the rate of 12 inches in about 30 seconds. With this rapid travelling the light of a lamp was quite inadequate, and a magnesium light produced by the burning of magnesium ribbon was used. The annexed diagram illustrates the sort of records that were got on the slow travelling and on the quick travelling plates. Fig. 1, that showing the result on a slow travelling plate, is actual size, representing a part of the plate only. Fig. 2 showing the result on a quick travelltng plate, is reduced to its present size from a length of 12 inches.

Of course the line of light that did the actual photographic

1. 2.

Fig. 1.—This is a half-size reproduction of tremors recorded on a quickly running plate. The chief points to be noticed are, first that the tremors increase and decrease in amplitude and that their period varies. May 28th, 1892.

Fig. 2.—This is portion of a diagram in which ½ inch equals 1 hour. It shows a deflection of the vertical, how tremors become large, and how maxima occur every 4 or 8 minutes. March 12th-13th, 1892.

J. M.

work was an image of the slit, which slit was made very narrow. I was surprised, in connection which this, to find how little difference it made what kind of objective was used to cast the image. A high class portrait objective was suggested, as on account of the perfect correction for both the spherical and chromatic aberration of the pencil's axial, or nearly so, I thought that the results would be much superior to those got with an inferior lens. To my surprise there was very little difference between the results got by the use of such a lens, and those got by the use of a single double-convex, or "crossed," lens, not even achromatized.

In 1887 MM. Fouqué and Michel Lévy described a set of experiments they had made to determine the rate of transmission of shock of an earthquake nature, produced by exploding dynamite, and in other ways, through different kinds of soil, using a photographic arrangement for recording the time and durations of vibrations. An incandesent electric lamp threw a beam of light at an angle through a lens and on to the face of mercury in a dish. The reflected beam of light was brought to focus on a revolving plate. If there were no motion, of course the light simply drew a circle. If there were any vibration, the beam of light was set in motion, and the circumference line of the circle was widened, and became indistinct. Thus the beginning, duration, and ending of the motion were indicated.

So much for what has already been done. It may be worth the necessary space to say a word or two about applications of photography that are, as yet, only contemplated.

In the case of all seismographs at present in use the "steady point" is a comparatively heavy mass of metal. There are no objections to this in the case of slight earthquakes but, in the case of great ones, when we have tilting the mass is liable to over-swing the mark and to exaggerate the motion. There is also the objection that it is never known for certain whether

SEISMOMETRICAL OBSERVATIONS FOR THE YEAR 1890.

ABSTRACTED BY JOHN MILNE.

CONTENTS.

1.—SEISMIC DISTURBANCES AND THEIR FREQUENCY.

During the year 1890, the total number of Earthquakes which occurred in this country was 845. A glance at the accompanying map shows the distribution of these disturbances.

The Provinces most frequently disturbed, were Higo,* Mu-

* In Higo 207 earthquakes were recorded. These were shocks following the great earthquake of July 1889. This explains the greater Seismic frequency for the whole country compared with previous years. In Tokyo we had 93 earthquakes. Such a great Seismic frequency is partly due to the fact, as it is suggested in every annual report, that even very feeble earthquakes have been observed by means of delicate instruments set up in the Meteorological Central Observatory.

sashi, Shimozuke, Nemuro, Kazusa, Shimosa, Hitachi, Sagami, Iwaki, Iwashiro, Satsuma, Awa, Idzu, Suruga, Kōzuke, Kai, Mikawa, Izumo, Rikuzen, Bungo, Ise, Owari, Mino, Kushiro, Iwami, Bingo, Tōtomi, Rikuchiu, Mutsu, Ugo, Kii, Yechigo, Shinano, Yechizen, Toshima, Aki, Ishikari, and Suo. (The arrangement is according to the frequency).

Each of the above provinces experienced more than five earthquakes, while the others had less than five during the year. In the following no earthquakes were recorded:—Inaba (1, W.), Hoki (4, N.E.), Mimasaka (1, N.), Oki, Nagato (6, N.E.), Suo (6, W.), Sanuki, Awa (6, W.), Tosa (7, S.), Iyo (2, centre), Bungo (1, W.), Chikuzen (6, S.), Hizen (7, N.), Chikugo (4, N.), Satsuma (3, W.), Iki, Tsushima, Teshio (nearly the whole), Ishikari (little, N.), Kitami (6, N.), and several islands.

2.—Number of Earthquakes in each Season.

The following table gives the number of earthquakes recorded during each month 1890:—

Month.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	ov.	Dec.	Total.	Aver-age.
Frequency.	86	65	83	80	93	66	59	55	48	63	98	49	845	70.3

The maximum frequency occurred in November, while the minimum was in September. The following table gives the frequency in each of season:—

Seasons.	Spring. March, April, May.	Summer June, July, August.	Autumn Sept., Oct., Nov.	Winter Dec., Jan., Feb.	Total.	Average.
Frequency.	256	180	209	200	845	211.2

The maximum seismic frequency occurred in Spring, while the minimum was in Summer. If we divide a year into the hot and cold seasons we have:—

Seasons.	Hot (from April to Sept. inclusive.)	Cold (from Oct. to March inclusive.)	Total.	Average.
Frequency	401	444	845	422.5

3.—Number of Earthquakes in each Hour.

The following table shows earthquake frequency in each hour:—

Months. Hours.	Forenoon. 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	Afternoon. 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	Total.
January ...	2	2	3	2	5	2	6	5	4	4	2	5	6	2	2	2	—	6	5	2	5	7	1	6	86
February...	3	3	3	3	5	5	5	2	1	3	5	2	1	1	—	2	1	1	2	—	4	2	7	4	65
March......	1	1	6	3	4	5	1	3	3	6	4	6	2	5	6	3	3	1	5	3	4	1	2	5	83
April	2	4	4	6	1	4	4	3	1	1	1	4	2	5	4	6	5	4	2	1	4	3	4	5	80
May	1	2	3	3	2	3	2	4	7	3	5	4	4	9	5	4	5	1	2	7	3	8	4	2	93
June	3	1	1	5	4	5	2	5	1	2	4	7	1	2	2	4	1	2	1	4	—	3	3	3	66
July........	2	2	9	2	1	3	2	1	2	5	1	—	1	3	7	1	4	3	—	—	1	4	2	3	59
August ...	2	1	3	3	3	1	1	1	—	4	3	1	1	3	6	6	3	2	3	2	2	—	1	3	55
September.	5	3	4	—	—	1	1	3	2	—	1	1	5	1	2	3	1	2	1	2	3	3	1	3	48
October ...	2	3	3	1	3	—	2	2	3	6	4	2	1	3	4	1	4	3	2	4	3	2	4	1	63
November.	11	6	5	4	2	2	4	3	3	3	3	—	5	7	2	5	3	—	4	9	3	4	5	5	98
December..	—	4	3	4	2	1	—	4	1	1	2	2	1	—	3	3	3	4	1	2	—	6	2	—	49
Total	34	32	47	36	32	32	30	36	28	38	35	34	30	41	43	40	33	29	28	36	32	43	36	40	845

From the above we see that the greatest number of earthquakes occurred between 2-3 a.m., and the next maximum frequency between 2-3 p.m. and between 9-10 p.m.; whereas the minimum was between 8-9 a.m. and between 6-7 p.m. and the next minimum between 5-6 p.m. If we took 6 o'clock as the limit between day and night, we should have at night a greater number of earthquakes than during the day by 11.

4.—Area of Seismic Disturbances and Intensity.

The area shaken by an earthquake varied from a mere local tract up to an area of several thousand square *ri*, depending chiefly on the intensity of the shock. In the following table, the number of earthquakes during the year has been classified according to the size of the area disturbed :—One square *ri* =5.9 sq. miles.

Area. Months.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Average.
Over 1,000 square *ri* ...	4	3	3	6	5	2	1	1	4	4	9	0	42	3.5
1,000—100 square *ri* ...	9	7	7	15	10	5	9	4	4	7	11	8	96	8.0
Under 100 square *ri* ...	73	55	73	59	78	59	49	50	40	52	78	41	707	58.9
Total	86	65	83	80	93	66	59	55	48	63	98	49	845	70.4

From the above we see that out of 845 earthquakes, 707 only disturbed areas less than 100 sq. *ri*, 96, areas of 100—1,000 sq. *ri*, and the remaining 42, areas of over 1,000 sq. *ri*. Among the last 42 earthquakes, 2 shook an area of over 5,000 sq. *ri* or about one fifth of the empire, and another shook over 9,000 sq. *ri* or about three-eighths of the empire.

5.—Number and Intensity of Earthquakes in each Province.

The number and intensity of earthquakes in each Province during the year 1890 were as follows :—

Provinces.	Frequency.	Severe.	Moderate.	Feeble.
Higo	207	2	15	190
Musashi	101	4	37	60
Shimozuke	95	1	28	66
Shimosa	67	2	23	42
Kazusa	65	1	21	43

Provinces.	Frequency.	Severe.	Moderate.	Feeble.
Hitachi	63	4	31	28
Nemuro	54	—	10	44
Iwaki	48	7	26	15
Sagami	43	5	28	10
Mikawa	36	—	20	16
Mino	36	1	15	20
Iwashiro	35	—	17	18
Rikuzen	34	2	12	20
Satsuma	31	—	2	29
Owari	30	1	21	8
Suruga	29	4	7	18
Idsu	25	7	6	12
Ise	25	2	11	12
Awa	24	1	8	15
Kozuke	21	1	9	11
Izumo	21	7	4	10
Iwami	21	1	4	16
Kii	21	—	5	16
Bungo	20	—	5	15
Kushiro	20	—	16	4
Ugo	19	3	15	1
Shinano	17	2	11	4
Kai	16	1	8	7
Bingo	15	—	7	8
Rikuchiu	13	1	6	6
Mutsu	13	5	5	3
Totomi	13	—	4	9
Yechigo	12	1	7	4
Yechizen	10	1	5	4
Aki	10	—	4	6
Oshima	10	3	4	3
Hiuga	8	1	3	4
Uzen	8	—	4	4
Ishikari	8	—	2	6

Provinces.	Frequency.	Severe.	Moderate.	Feeble.
Bichiu	7	1	1	5
Chikugo	6	—	5	1
Suo	6	—	3	3
Iyo	6	1	2	3
Shiribeshi	6	—	4	2
Chishima	5	—	2	3
Omi	5	1	1	3
Shima	5	—	—	5
Bizen	5	—	5	—
Hoki	5	—	2	3
Iga	4	1	1	2
Wakasa	4	1	1	2
Kaga	4	—	1	3
Yechiu	4	—	1	3
Hizen	4	—	2	2
Hitaka	4	2	1	1
Iburi	3	—	—	3
Hida	3	—	1	2
Tango	3	1	—	2
Harima	3	1	1	1
Awa	3	—	3	—
Tosa	3	—	1	2
Buzen	3	1	1	1
Tokachi	2	—	—	2
Yamashiro	2	1	1	—
Osumi	2	—	—	2
Nagato	2	—	1	1
Mimasaka	2	—	1	1
Tanba	2	1	1	—
Yamato	2	1	—	1
Noto	2	—	1	1
Awaji	2	—	2	—
Kawachi	2	1	1	—
Izumi	1	1	—	—

Provinces.	Frequency.	Severe.	Moderate.	Feeble.
Settsu	1	1	—	—
Tajima	1	—	1	—
Inaba	1	—	1	—
Sado	1	—	—	1

Thus Higo had 207, Musáshi 101, Shimozuke 95, Shimosa 67, Kazusa 65, Hitachi 63, and Nemuro 54 earthquakes this year, while Izumi, Settsu, Tajima, Inaba, and Sado had each of them only one earthquake respectively.

6.—Intensity of Earthquakes.

Of the 845 earthquakes in the year 1890, there were 49 severe disturbances, 264 which were moderate, and 532 which were feeble. Thus 6 per cent. of the total number of earthquakes in the year were severe, 31 per cent. moderate, and 63 feeble. The provinces shaken by severe shocks were as follows :—

No. of Earthquakes.	Provinces.
7	Iwaki, Idsu, Izumo ;
5	Sagami, Mutsu ;
4	Hitachi, Musashi, Suruga ;
3	Ugo, Oshima ;
2	Shimosa, Rikuzen, Hitaka, Shinano, Ise, Higo ;
1	Yechizen, Yechigo, Rikuchiu, Kozuke, Shimozuke, Kazusa, Awa, Kai, Mino, Owari, Iga, Omi, Yamashiro, Yamato, Kawachi, Izumi, Settsu, Harima, Tanba, Tango, Iwami, Bichiu, Wakasa, Iyo, Buzen, Hiuga.

Among the most severe earthquakes, we may count the one which occurred in Idsu and its neighbourhood on April 16th, the one in *Shin-yetsu* and neighbourhood on January 7th, the one in Gokinai on March 19th, the one in Hokkaido and *Sanriku* on November 17th, the one in Iwashiro and its neighbourhood on June 18th, the one in Mutsu and its neigh-

bourhood on November 7th, the one in Sagami and its neighbourhood on September 6th, the one in Izumo and its neighbourhood on January 30th, and lastly the one in Hiuga and its neighbourhood on October 10th. By these earthquakes, houses and buildings were damaged, stone lanterns and tombstones overthrown, articles on shelves thrown down, pendulum clocks stopped, and the area shaken was of vast extent.

7.—Table of Earthquakes (Monthly).

In the following table, provinces are classified according to frequency of earthquakes in each month. The days of occurrence and areas of severe earthquakes, together with the day, area, and provinces visited by the earthquake which shook the most extenives area in each month are given :—

January.

Seismic Frequency.		Severe Earthquakes.			Most Extensive Earthquake.		
Number of Earthquakes.	Provinces.	No.	Days.	Provinces.	Days.	Area.	Provinces.
16-15	Higo.	1	7th	Shinano, Yechigo.	7th	5,850 sq. *ri.*	Shinano, Yechigo, Kozuke, Shimozuke, Iwashiro, Iwaki, Hitachi, Shimosa, Kazusa, Musashi, Sagami, Kai, Suruga, Idsu, Totomi, Mikawa, Owari, Ise, Omi, Mino, Yechizen, Hida, Kaga, Yetchiu, Noto, Sado.
14-13	Izumo.	2	7th	Shinano.			
8-7	Iwami.	3	30th	Izumo, Iwami.			
6-5	Bingo, Musashi, Kazusa.	4	30th	Izumo.			
4-3	Shimosa, Mikawa, Sagami, Suruga, Shinano, Owari, Mino, Kii, Kaga, Yechigo, Ugo, Shimozuke, Aki, Nemuro.	5	30th	Izumo.			
		6	30th	Izumo.			
		7	30th	Izumo.			
		8	30th	Izumo.			
2-1	Hitachi, Kozuke, Kai, Iwaki, Iwashiro, Uzen, Idzu, Hida, Noto, Yechiu, Tango, Bichiu, Hoki, Awa, Rikuzen, Totomi, Ise, Omi, Tanba, Yechizen, Wakasa, Sado, Bizen, Suo, Iyo, Bungo, Hizen, Chikugo, Satsuma, Osumi.	9	30th	Izumo.			

February.

Number of Earthquakes.	Provinces.	No.	Days.	Provinces.	Days.	Area.	Provinces.
8-7	Higo.	1	20th	Bichiu.	21st	1,090 sq. *ri.*	Musashi, Sagami, Kozuke, Shimozuke, Hitachi, Shimosa.
6-5	Shimozuke, Kazusa, Musashi, Shimosa, Hitachi, Izumo, Satsuma.						
4-3	Iwaki, Sagami, Kii, Nemuro.						

Seismic Frequency.		Severe Earthquakes.			Most Extensive Earthquakes.		
Number of Earthquakes.	Provinces.	No.	Days.	Provinces.	Days.	Area.	Provinces.
2·1	Awa, Suruga, Kai, Bizen, Bichiu, Bingo, Hoki, Iwami, Kozuke, Iwashiro, Rikuzen, Ugo, Yechigo, Mino, Mikawa, Owari, Omi, Yamashiro, Mimasaku, Aki, Shiribeshi, Ishikari, Kushiro, Buzen.						
				MARCH.			
40·39	Higo.	1	6th	Higo.	19th	4,310 sq. *ri.*	Yamashiro, Yamato, Kawachi, Izumi, Settsu, Iga, Omi, Ise, Owari, Mino, Yechizen, Shinano, Mikawa, Totomi, Suruga, Kai, Shima, Kii, Awaji, Harima, Tanba, Wakasa, Tango, Tajima, Inaba, Mimasaka, Bizen, Bichiu.
6·5	Musashi, Shimozuke.	2	6th	Higo.			
4·3	Hitachi, Kuzusa, Shimosa, Iwaki, Owari, Ise, Nemuro.	3	19th	Yamashiro, Yamato, Kawachi, Izumi, Settsu, Omi, Mino, Owari, Ise, Iga, Harima, Tanba, Tango, Wakasa, Yechizen.			
2·1	Sagami, Suruga, Mikawa, Mino, Omi, Bizen, Mutsu, Rikuzen, Iwashiro, Kozuke, Awa, Idsu, Totomi, Shima, Shinano, Hida, Yechiu, Kaga, Yechizen, Wakasa, Yamashiro, Iga, Kii, Kawachi, Izumi, Settsu, Awaji, Harima, Tanba, Tango, Tajima, Inaba, Bichiu, Iwami, Hiuga, Bungo, Chikugo, Kushiro, Tokatsu, Chishima, Hitaka, Ishikari, Iburi, Toshima.	4 5	28th 31st	Iwashiro, Hitachi. Hitaka.			

			APRIL.				
16·15	Higo, Musashi.	1	16th	Idsu, Suruga, Sagami, Musashi, Kazusa, Awa.	16th	4,740 sq. *ri.*	Idsu, Suruga, Sagami, Musashi, Kazusa, Awa, Shimosa, Hitachi, Shimozuke, Kozuke, Kai, Totomi, Mikawa, Owari, Iwashiro, Iwaki, Shinano, Hida, Mino, Ise.
14·13	Idsu.						
12·11	Sagami.						
10·9	Kazusa, Shimosa, Awa.	2	17th	Idsu, Sagami, Musashi.			
8·7	Suruga.						
6·5	Shimozuke, Iwashiro, Mino, Totomi, Hitachi, Mikawa, Owari, Nemuro.	3	17th	Idsu, Suruga, Sagami.			
		4	17th	Idsu.			
4·3	Kai, Iwami, Shinano, Kozuke, Bungo.						
2·1	Aki, Bingo, Iwaki, Ugo, Mutsu, Uzen, Rikuchiu, Rikuzen, Ise, Kii, Bichiu, Suo, Nemuro, Kushiro, Chishima, Bungo, Satsuma, Iyo.						
			MAY.				
34·33	Higo.	1	1st	Idsu.	24th	2,020 sq. *ri.*	Hitachi, Shimosa, Kazusa, Awa, Shimozuke, Musashi, Kai, Sagami, Kazusa, Iwaki.
14·13	Musashi.	2	15th	Idsu.			
10·9	Satsuma.	3	16th	Shimosa.			
8·7	Hitachi, Nemuro.	4	21st	Shimozuke, Kozuke.			
6·5	Shimozuke, Shimosa, Iwaki, Iwashiro.	5	25th	Iwaki.			
4·3	Kazusa, Sagami, Idsu, Mikawa, Mino.						
2·1	Kozuke, Rikuzen, Suruga, Awa, Kai, Owari, Shinano, Yechigo, Uzen, Mutsu, Nagato, Kushiro, Oshima, Ishikari, Bungo, Chikugo, Hizen.						

June.

Seismic Frequency.		Severe Earthquakes.			Most Extensive Earthquakes.		
Number of Earthquakes.	Provinces.	No.	Days.	Provinces.	Days.	Area.	Provinces.
26-25	Higo.	1	3rd	Iyo.	18th	5,370 sq. *ri*.	Iwaki, Rikuzen, Uzen, Ugo, Rikuchiu, Mutsu, Iwashiro, Kozuke, Shimozuke, Hitachi, Shimosa, Kazusa, Musashi.
6·5	Nemuro, Musashi.	2	7th	Mutsu.			
4·3	Hitachi, Rikuzen, Owari, Mikawa, Bungo, Satsuma, Kushiro.	3	18th	Iwaki, Rikuzen.			
2·1	Shimozuke, Iwashiro, Iwaki, Rikuchiu, Mutsu, Uzen, Aki, Suo, Shimosa, Kazusa, Awa, Sagami, Kozuke, Yechigo, Ugo, Shinano, Mino, Ise, Bungo, Nagato, Oshima, Hitaka, Tokachi, Chishima, Iyo, Buzen, Chikugo, Hiuga.	4	29th	Buzen.			

July.

Number of Earthquakes.	Provinces.	No.	Days.	Provinces.	Days.	Area.	Provinces.
20·19	Higo.	1	3rd	Suruga.	19th	2,010 sq. *ri*.	Hitachi, Iwaki, Iwashiro, Shimozuke, Kozuke, Musashi, Shimosa, Kazusa.
12·11	Musashi, Shimozuke.	2	19th	Hitachi.			
6·5	Hitachi, Shimosa.						
4·3	Sagami, Bungo, Satsuma.						
2·1	Kazusa, Iwaki, Ise, Idsu, Suruga, Kozuke, Iwashiro, Yechigo, Kii, Aki, Suo, Iwami, Hizen, Buzen, Hiuga, Chishima.						

AUGUST.

20-19	Higo.	1	5th	Idsu.	5th	1,600 sq. *ri*.	Idsu, Awa, Kazusa, Musashi, Sagami, Kai, Suruga, Shinano, Totomi, Mikawa, Owari, Mino.
8-7	Musashi.						
6-5	Shimozuke.						
4-3	Shimosa, Hitachi, Nemuro, Satsuma.						
2-1	Kazusa, Iwaki, Suruga, Mikawa, Totomi, Shinano, Kai, Idsu, Sagami, Awa, Rikuzen, Owari, Ise, Yamato, Kii, Harima, Mino, Yechizen, Yechiu, Wakasa, Bingo, Iwami, Suo, Bungo.						

SEPTEMBER.

14-13	Higo.	1	6th	Sagami, Musashi, Suruga, Kai.	6th	3,030 sq. *ri*.	Sagami, Suruga, Kai, Musashi, Awa, Kazusa, Shimosa, Hitachi, Shimozuke, Kozuke, Shinano, Idsu, Totomi.
8-7	Shimozuke.						
6-5	Kazusa, Hitachi, Shimosa, Musashi.	2	30th	Shimosa, Hitachi, Iwaki.			
4-3	Kozuke, Sagami, Awa, Iwaki, Iwashiro, Nemuro.						
2-1	Idsu, Suruga, Mikawa, Owari, Ise, Yechigo, Rikuchiu, Rikuzen, Mutsu, Ugo, Uzen, Kai, Totomi, Shinano, Mino, Shima, Kawachi, Kii, Satsuma, Ishikari.						

OCTOBER.

Seismic Frequency.		Severe Earthquakes.			Most Extensive Earthquakes.		
Number of Earthquakes.	Provinces.	No.	Day.	Provinces.	Day.	Area.	Provinces.
10·9	Shimozuke.	1	10th	Hiuga.	6th	3,400 sq. *ri.*	Hitachi, Kazusa, Shimosa, Awa, Musashi, Sagami, Shimozuke, Kozuke, Iwaki, Iwashiro, Rikuzen.
8·7	Musashi, Shimosa.	2	12th	Oshima.			
6·5	Higo, Hitachi, Kazusa, Iwaki, Yechizen.	3	15th	Iwaki.			
4·3	Sagami, Iwashiro, Awa, Rikuzen, Bungo, Hiuga.						
2·1	Kozuke, Kai, Shinano, Yechigo, Ugo, Rikuchiu, Mutsu, Totomi, Mikawa, Mino, Ise, Wakasa, Bingo, Iwami, Nemuro, Toshima, Ishikari, Kushiro, Awa, Tosa, Iyo, Chikugo, Osumi, Satsuma.						

NOVEMBER.

Number of Earthquakes.	Provinces.	No.	Day.	Provinces.	Day.	Area.	Provinces.
12·11	Shimozuke.	1	4th	Shimosa.	17th	9,190 sq. *ri.*	Mutsu, Rikuchiu, Oshima, Hitaka, Tokachi, Iburi, Ugo, Rokuzen, Iwashiro, Iwaki, Hitachi, Shimozuke, Shimosa, Musashi, Kazusa, Shiribeshi, Ishi-
10·9	Musashi, Hitachi, Iwaki, Nemuro.	2	5th	Iwaki.			
		3	5th	Iwaki.			
8·7	Shimosa, Kazusa, Iwashiro, Rikuzen.	4	5th	Iwaki.			
		5	7th	Mutsu, Ugo, Oshima.			
6·5	Higo, Ugo, Rikuchiu, Owari, Mino, Oshima, Kushiro.	6	7th				
		7	12th	Mutsu, Ugo.			
4·3	Mutsu, Mikawa, Ise, Sagami, Kozuke, Shirebeshi, Ishikari,	8	14th	Hitachi.			
		9	17th	Sagami, Musashi.			

	Hitaka, Iburi, Awa, Shinano, Suruga, Totomi, Iga, Shima, Omi, Kii, Yechizen, Harima, Awaji, Idsu, Kai, Uzen, Bungo, Awa, Tosa.	10 11	27th 29th	Hitaka, Oshima, Mutsu, Rikuchiu. Mutsu. Ugo.			kari, Kushiro, Nemuro, Kitami, Teshio.

DECEMBER.

8·7	Nemuro,	1	20th	Ise.	18th	720 sq. *ri*.	Mikawa. Owari, Mino, Ise, Shima, Iga.
6·5	Ise.						
4·3	Owari, Kii, Shimozuke, Higo.						
2·1	Mikawa, Mino, Shima, Iga, Sagami, Musashi, Shimosa, Suruga, Iwashiro, Iwaki, Riukuzen, Kazusa, Awa, Hitachi, Rikuchiu, Yechigo, Idsu, Shinano, Yechizen, Bingo, Izumo, Iwami, Hoki, Kushiro, Satsuma, Bungo, Awa.						

8.—Notes on Special Earthquakes.

The following short accounts only refer to the most notable earthquakes or to characteristic ones which occurred during the year 1890 :—

1. The earthquake on January 7th occurred at 3.43 p.m. The area affected on that day was very wide, extending from Iwashiro, Iwaki, Hitachi, Shimosa, and Kazusa in the east, to Ise, Omi, and Yechizen in the west, and reaching far out into the sea towards the south and north. The area therefore included 26 provinces. Among the rest, Shinano (3½, N.W.) Yechigo (little, W.), which cover an area of 360 sq. *ri*, were severely disturbed ; especially an area of 30 sq. *ri* extending to several *guns* of Kami-Mizuuchi, Higashi-Chikuma, Kita-Akumo, and Saragumi was most severely shaken and suffered great damage. A report from the Nagano Observatory says that the disturbed area extended from Hijiri-yama in the east, to Aogai-tōge in the west, and from Ikuzaka-mura in the south to Mushikura-yama in the north, chiefly extending along the river Sai more than at the east-west. It is said that during this earthquake, in Ikuzaka, Higashi-Chikuma-gōri, buildings and godowns were greatly damaged, mountains gave way, roads were destroyed, and tombstones nearly overthrown ; that in Hirotsu, Kita-Akumogōri, earth slipped from houses, and buildings were inclined, articles were thrown down, doors overthrown, and land on the mountain-side was fissured like the markings on the shell of a tortoise ; that in Shinoda, Saragumi-gōri, rents were made in walls, and sometimes stone lanterns and tombstones overthrown ; that in Tsuwa and Oyama, Kami-Mizuuchi-gōri, articles were knocked down, slight cracks were made in walls, and people fled out of doors, but in the latter, a great number of godowns suffered, rents were made in walls, sometimes even moving their positions, and in some spots water burst out on the surface of the earth or a long fissure was made generally running from South-West to the North-east, the exact direction depending

on the nature of the ground. In Kita-Ogawa, Kami-Mizuuchi-gōri, there were shiftings of rocks, roads buried, gravestones thrown over, cracks made in walls of godowns; the beams of a house were shaken off and articles were knocked down. In the Nagano Observatory near the spot most severely shaken, the pendulum clock was stopped. Besides this, in Higashi-Chikuma-gori, Minami and Kita-Akumo-gōri, Saragumigori, Kami and Shimo-Mizuuchi-gōri, Kami and Shimo-Takaigōri, and Uyeshina-gōri, people fled out of doors and articles were overthrown. In some spots in Yechigo, it is said hanging clocks were shaken down, pendulum clocks stopped, and a part of the walls broken down. Among the moderately shaken areas may be mentioned Shinano (6½, S.) Mino (2, N.E.), Hida (9, E.), Yechiu (9, E.), Noto (4, E.), Yechigo (7, S.W.), Iwashiro (1, S.W.), Kōzuke, Shimozuke (1½, W.), Musashi (4, N.W.), and Kai (7, N.), amounting to an area of 2,310 sq. *ri;* and among the areas of feeble shock may be mentioned Musashi (6, E.), Sagami, Izu, Suruga, Tōtomi, Mikawa, Owari, Kaga, Sado, Kai (3, S.), Ise (4, N.), Omi (3, E.), Mino (8, S.W.), Yechizen (8, E.), Hida (1, W.), Noto (6, W.), Hitachi (6, W.), Yechigo (3, N.E.), Iwashiro (5, centre), Iwaki (1, S.W.), Shimozuke (8½, E.), Shimoza (7, W.), and Kazusa, (4, W.), amounting to an area of 3,180 sq. *ri.* The total area affected was 8,850 sq. *ri.* As to the nature of the motion, we had reports saying that the horizontal motion was most general, whereas the up and down motion was felt in but few of the shaken areas. Among the areas shaken most severely we have Kami-Takai-gōri, Shinano; and Nish-Kubiki-gori, Yechigo. Among the moderately or feebly shaken areas, we may mention Kami-Ina-gōri, Shinano; Nish-Chikuma-gōri, Shinano; Minami-Kanbara-gōri, Yechigo; Tone-gōri, Kozuke, and Hokkai-gōri, Mikawa. The motion was generally slow in all places, excepting in the neighbourhoods of the severely shaken districts. The direction of the motion was generally towards the origin of the disturb-

ance, but sometimes it was at right angles to it or indefinite. As to the duration of the motion it is said that in the severely affected regions the shock had a short duration, while in the feebly affected districts the duration was relatively long. The severe earthquakes were followed by several feeble shocks; one shock took place at 3.48 p.m. on the same day and it was felt in 17 provinces, viz., Shinano, Kai, Hida, Yechiu, Kaga, Noto, Yechigo (7, W.), Kozuke (nearly the whole), Musashi (6, W.), Sagami (7, N.), Izu (little, N.), Suruga (nearly the whole), Tōtōmi (4, N.), Mikawa (6, N.), Owari (7, N.), Mino (8, N.E.), and Yechizen (3, W.), occupying an area of 3,730 sq. *ri*; and it is said that though feeble, Yena-gōri, Mino; and Shimo-Ina-gōri, Shinano, were affected by this earthquake even more severely than by the foregoing one.

2. The earthquake on March 19th, which occurred at 3.15 a.m.—This earthquake was felt in 31 provinces, Go-Kinai*, Omi, Wakasa, Tango, Tanba, Tajima, Harima, Inaba, Bizen, Iga, Ise, Shima, Kii, Yechizen, Mino, Owari, Mikawa, Kaga, Hida, Tōtōmi, Awaji, Yechiu (7, W.,) Shinano (6, S.W.), Kai (3, W.), Suruga (5, W.), Mimasaka (5, E.), and Bichiu (2, E.), covering an area of 4,110 sq. *ri.* It especially was felt in 15 provinces Yamashiro, Kawachi, Settsu, Wakasa, Omi, Iga, Tango (15, E.), Tanba (9, E.), Harima (2, E.), Izumi (3, N.), Yamato (4, N.), Ise (5, N.), Mino (7, S.W.), and Yechizen (7, S.), occupying an area of 1,360 sq. *ri*; moderately in the provinces Mikawa, Shima, Awaji, Tango (5, W.), Tajima (7, E.), Harima (6, centre), Tanba (1, W.), Izumi (7, S.), Kii (7, N.), Yamato (6, S.), Ise (5, S.), Owari (1, S.), Tōtōmi (3, W.), Shinano (1, W.), Hida (5, S.W.), and Yechizen (3, N.), occupying an area of 1,620 sq. *ri*; and feebly in provinces Bizen; Inaba (9, S.E.), Kaga (2, N.E.), Yechiu (7, W.), Hida (5, N.E.), Shinano (5. centre), Kai (3, W.), Suruga (5, W.), Tōtōmi (7, E.), Kii (3, S.), Tajima (3, W.), Mimasaka (5, E.), Bichiu (2, E.) and Harima

* The five provinces of Yamashiro, Yamato, Kawachi, Izumi, Settsu, being the Imperial domain.

(2, W.), amounting to an area of 1,130 square *ri*. It is said that in the last mentioned areas, here and there, there were persons who felt no shocks at all. As to the nature of the motion, we were informed that a little up and down motion was felt in each of the shaken areas, but it seems that it was generally horizontal. In may places roaring sounds were heard, and also feeble shocks were felt every two or three minutes. Thus we see that the areas affected by this earthquake were very extensive, fortunately however, causing no damage.

3. The earthquake on April 16th, which occurred at 9.30 p.m:—On this day an earthquake was felt in 20 provinces: Izu, Suruga, Sagami, Musashi, Kazusa, Awa, Shimosa, Hitachi, Shimozuke, Kozuke, Kai, Tōtomi, Mikawa, Owari. Iwaki (9, S.), Iwashiro (6, S.E.), Shinano (9, S.), Hida (5, S.E.), Mino (7, E.), and Ise (1, N.E.). Among the severely shaken areas may be mentioned Idzu, Suruga (1, E.), Sagami (8, S.), Musashi (1, S.), Kazusa (4, S.W.), and Awa, amounting to an area of 290 sq. *ri*. Among others, Shimoda and Miyakeshima in the province of Izu were most severely affected. In the latter, a shock began with a thundering noise heard at about half-past nine in the evening. Its direction was south-east; and by the shaking, which was up and down, back and forth, doors fell down, articles on shelves were knocked over, braziers were upset, pendulum clocks stopped, and the sea-shore gave way, destroying Okubo-hama, Kanzaki, burying roads, and thereby stopping traffic. Besides this, in several other villages many roads were destroyed and cracks were made on the surface of the earth; which are said to have extended towards the south-east. In Miyake-shima, after this earthquake, light shocks frequently happened every ten minutes for some fifty times. Severe shocks occurred on the 17th at 1 a.m., and at 6 a.m., but the number of shocks gradually decreased to once every 20 minutes or every hour. On the 18th they occurred about once in two hours. Again, among the mode-

rately shaken areas may be mentioned Suruga (9, W.), Tōtomi, Kai, Sagami (2, N.), Musashi (9, N.), Kazusa (6, N.E.), Shimosa, Hitachi (7, S.), Shimozuke (2, S.), Kozuke (2, S.), Shinano (3, S.E.), and Mikawa (6, E.), amounting to an area of 2,150 sq. *ri*. Among the feebly shaken areas may be mentioned, Kozuke (8, N.), Shimozuke (8, N.), Hitachi (3, N.), Iwaki (9, S.), Iwashiro (6, S.E.), Shinano (5, centre), Hida (5, S.E.) Mino (7, E.), Mikawa (4, W.), Owari, and Ise, (1, N.E.), occupying an area of 2,300 sq. *ri*. The total area shaken was 4,740 sq. *ri*.

4. The earthquake on November 17th occurred at about 9h. 31′ a.m. The area affected on the day was the greatest area shaken in 1890, extending from Hokkaido in the north, to Shimozuke, Musashi, and Kazusa in the south. Among the severely shaken areas may be mentioned Toshima (2, E.), Iburi (little, S.E.), Hitaka (8, S.), Tokatsu (2, S.), Mutsu (4, E.), and Rikuchiu (1, N.E.), occupying an area of 880 sq. *ri*; among the moderately shaken areas may be mentioned Mutsu (6, W.), Rikuchiu (9, S,W.), Ugo (5, N.E.), Rikuzen (6, N.E.). Toshima (8, W.), Shiribeshi (7, S,), Iburi (nearly the whole), Hitaka (2, N.), Ishikari (4, S.), Takatsu (8, N.), Kushiro (6, S.E), and Nemuro (1, S.), occupying an area of 4,230 sq. *ri*; among the feebly shaken areas may be mentioned Nemuro (8, centre), Kushiro (4, N.W.), Kitami (3, S.), Ishikari (6, N.), Teshio (little, S.), Shiribeshi (3, N.), Ugo (5, S.W.), Rikuzen (4, S.W.), Uzen (nearly the whole), Iwashiro (8, E.), Iwaki, Hitachi, Shimosa, Shimozuke (nearly the whole), Musashi (3, E.), and Kazusa (4, N.), occupying an area of 4,080 sq. *ri*. Thus the total area shaken was 9,190 sq. *ri*, beneath the ocean, Eastward from Rikuchu and Mutsu and Hokkaido.

Earthquake Observations made at the Meteorological Central Observatory, Tokyo.

During the year 1890, the number of earthquakes observed

at the Meteorological Central Observatory was 93. The following table shows at a glance the date, direction, intensity, etc., of these earthquakes :—

9.—TABLE OF EARTHQUAKES OBSERVED IN TOKYO DURING THE YEAR 1890.

Date.	Time of Occurrence.	Duration.	Horizontal Motion. Direction.	Max. Range in mm.	Max. Vel. per Sec. in mm.	Max. Accel. per Sec. in mm.	Vertical Motion. Max. Amplitude in mm.
Jan.	h. m. s.	m. s.					
7th	7 44 37 a.m.	40	S.N.	little	—	—	—
7th	3 43 25 p.m.	5 0	S.E. to N.W.	2.0	2.9	8.6	—
12th	4 15 33 a.m.	—	—	little	—	—	—
29th	11 28 3 p.m.	57	E. to W.	0.3	1.3	11.3	—
30th	8 35 31 a.m.	—	—	little	—	—	—
Feb.							
13th	9 48 16 p.m.	30	E. to W.	0.2	3.1	9.6	—
18th	5 31 10 a.m.	—	—	little	—	—	—
	9 50 6 a.m.	—	—	little	—	—	—
21st	2 44 13 a.m.	40	E. to W.	little	—	—	—
24th	0 47 2 a.m.	30	S.E. to N.W.	0.2	0.8	6.4	—
Mar.							
7th	4 21 12 a.m.	20	E. to W.	0.2	1.3	16.9	—
11th	11 7 2 a.m.	30	—	little	—	—	—
	7 53 49 p.m.	1 0	E.S.E. to W.N.W.	0.4	6.3	198.4	—
18th	3 16 40 p.m.	20	—	little	—	—	—
26th	6 57 55 a.m.	—	—	little	—	—	—
28th	2 22 37 p.m.	—	—	little	—	—	—
April.							
5th	0 20 0 p.m.	—	—	little	—	—	—
11th	3 8 2 a.m.	1 5	E. to W.	0.4	1.4	9.8	—
16th	9 34 47 p.m.	7 0	S.E. to N.W.	22.4	24.3	52.7	0.2
	11 40 3 p.m.	—	—	little	—	—	—
April.							
17th	4 56 45 a.m.	8 0	S.E. to N.W	7.8	6.4	10.5	little
	5 11 3 a.m.	—	—	little	—	—	—
	6 42 36 a.m.	6 30	S.E. to N.W.	3.3	3.0	5.4	—
	3 31 38 p.m.	—	—	little	—	—	—
	10 25 18 p.m.	3 30	S.E. to N.W.	1.2	1.5	3.7	—
18th	5 38 37 p.m.	—	—	little	—	—	—
	7 15 57 p.m.	—	—	little	—	—	—
	11 3 0 p.m.	—	—	little	—	—	—
19th	9 45 52 p.m.	—	—	little	—	—	—
	1 7 37 p.m.	—	—	little	—	—	—
27th	8 31 48 p.m.	—	—	little	—	—	—

Date.	Time of Occurrence.	Duration.	Horizontal Motion.				Vertical Motion.
			Direction.	Max. Range in mm.	Max. Vel. per Sec. in mm.	Max. Accel. per Sec. in mm.	Max. Amplitude in mm.
May.							
1st	3 56 25 a.m.	—	—	little	—	—	—
	8 38 50 a.m.	—	—	little	—	—	—
	7 40 10 p.m.	—	—	little	—	—	—
	9 59 21 p.m	—	—	little	—	—	—
4th	2 29 17 p.m.	1 45	S.N.	0 2	0.4	0.2	—
7th	10 4 38 a.m.	20	E.W.	little	—	—	—
8th	8 35 56 a.m.	1 0	S.W. to N.E.	0.3	1.2	9.6	—
10th	6 49 23 a.m.	10	S.W.	little	—	—	—
15th	2 36 9 p.m	5 30	N.W. to S.E.	0.9	1.3	3.8	—
21st	0 9 54 p.m.	35	E.W.	0.2	1.6	2.6	—
24th	1 39 33 p.m	1 30	N.W. to S.E.	0.3	1.9	24.1	—
25th	8 54 45 a.m.	—	—	little	—	—	—
27th	6 49 40 p.m.	—	—	little	—	—	—
31st	8 42 25 p.m.	—	—	little	—	—	—
June.							
7th	11 29 53 a.m.	—	—	little	—	—	—
15th	4 30 15 p.m.	12	E.W.	little	—	—	—
18th	1 45 22 p.m.	3 0	N.E. to S.W.	0.6	1.5	7.5	little
26th	9 3 13 a.m.	—	—	little	—	—	—
28th	5 0 40 a.m.	50	S.E. to N.W.	0.7	3.1	27.5	—
July.							
2nd	2 15 9 a.m.	—	—	little	—	—	—
3rd	11 5 55 p.m.	—	—	little	—	—	—
8th	2 50 30 p.m.	20	N.E. to S.W.	0.3	1.0	6.7	—
9th	9 53 1 p.m	1 0	W.N.W. to E.S.E	0.3	0.6	2.4	—
11th	9 1 5 a.m.	—	—	little	—	—	—
14th	4 10 49 p.m.	50	S.N.	little	—	—	—
15th	8 15 51 p.m.	20	S.W.	0.3	3.1	64.1	—
18th	0 35 46 a.m.	10	S.W.	little	—	—	—
July.	h. m. s.	m.s.					
19th	4 18 50 p.m.	50	W.N.W. to E.S.E.	0.2	1.6	25.6	little
20th	9 15 45 p.m.	—	—	little	—	—	—
25th	3 51 13 a.m.	—	—	little	—	—	—
	2 57 25 p.m.	—	—	little	—	—	—
Aug.							
2nd	11 6 35 p.m.	1 8	S.N.	0.2	0.5	2.7	—
4th	9 38 14 a.m.	—	—	little	—	—	—
5th	1 46 21 p.m.	2 14	S.E. to N.W.	0.3	0.6	2.4	—
7th	7 27 13 a.m.	—	—	little	—	—	—
11th	1 43 45 p.m.	—	—	little	—	—	—
21st	6 5 16 p.m.	—	—	little	—	—	—
29th	11 34 31 a.m.	—	—	little	—	—	—

Date.	Time of Occurrence.	Duration.	Horizontal Motion.				Vertical Motion.
			Direction.	Max. Range in mm.	Max. Vel. per Sec. in mm.	Max. Accel. per Sec. in mm.	Max. Amplitude in mm.
Sept.							
5th	7 57 19 p.m.	3 0	S.N.	0.8	1.0	2.5	—
6th	0 11 55 a.m.	1 40	S.S.W. to N.N.E.	0.6	1.9	12.0	—
17th	6 20 57 p.m.	55	S.W. to N.E.	0.2	1.0	10.0	—
30th	7 24 54 p.m.	2 0	S.N.	0.2	0.6	3.6	—
Oct.							
6th	4 36 50 p.m.	2 45	E.N.E. to W.S.W.	0.7	1.6	7.3	—
10th	9 33 30 a.m.	—	S.N.	little	—	—	—
12th	9 45 30 a.m.	—	S.N.	little	—	—	—
16th	4 5 47 a.m.	30	—	little	—	—	—
17th	8 35 18 p.m.	36	E.W.	little	—	—	—
19th	2 33 45 p.m.	30	E.W.	0.3	4.7	147.3	—
	8 34 14 p.m.	—	—	little	—	—	—
29th	10 36 51 p.m.	15	E.W.	little	—	—	—
Nov.							
2nd	9 30 30 a.m.	—	—	little	—	—	—
5th	0 44 29 a.m.	30	E.W.	little	—	—	—
14th	2 21 17 a.m.	1 6	S.E. to N.W.	0.3	1.6	17.1	little
16th	3 8 6 p.m.	30	E.W.	little	—	—	—
17th	9 31 38 a.m.	50	E.W.	little	—	—	—
22nd	10 50 31 p.m.	—	—	little	—	—	—
25th	7 1 0 p.m.	1 0	S.W. to N.E.	0.2	3.1	96.1	—
27th	0 24 39 a.m.	15	S.E. to N.W.	little	—	—	—
	7 33 48 p.m.	—	—	little	—	—	—
29th	7 30 40 p.m.	—	—	little	—	—	—
Dec.							
11th	5 34 53 p.m.	30	S.E. to N.W.	0.2	2.1	44.1	—
24th	7 22 27 a.m.	—	—	little	—	—	—

10.—Earthquake frequency per Month.

During the year 1890, the number of earthquakes in each month was as follows :—

Months.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Frequency.	5	5	6	15	14	5	12	7	4	8	10	2	93

From the above it is seen that the maximum frequency occurred in April, and the minimum was in December.

11.—Earthquake frequency per Season.

Year.	Spring.	Summer.	Autumn.	Winter.	Average.
1890	35	24	22	12	23

The maximum frequency was in spring, while the minimum was in winter.

12.—FREQUENCY DURING HOT AND COLD PERIODS.

Year.	Hot.	Cold.	Average.
1890	36	57	46

From the above it is seen that the average number of earthquakes during both periods was 46, and we had in the hot period a greater number of earthquakes than during the cold period by 21.

13.—Hourly frequency of Earthquakes.

The number of earthquakes in each hour during the year will be found from the following table:—

	Forenoon.												Afternoon.												
Mths. Hs.	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	Total.
Jan.......	—	—	—	—	1	—	—	1	1	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1...	5
Feb.......	1	—	1	—	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1	—	—...	5
March ...	—	—	—	—	1	—	1	—	—	—	—	1	—	—	1	1	—	—	—	1	—	—	—	—...	6
April ...	—	—	—	1	1	1	1	—	—	1	—	—	1	1	—	1	—	1	—	1	1	1	1	2...	15
May......	—	—	—	1	—	—	1	—	3	—	1	—	1	1	2	—	—	—	1	1	1	1	—	—...	14
June ...	—	—	—	—	—	1	—	—	—	1	—	1	—	1	—	—	1	—	—	—	—	—	—	—...	5
July......	1	—	1	1	—	—	—	—	—	1	—	—	—	—	2	—	2	—	—	—	1	2	—	1...	12
Aug. ...	—	—	—	—	—	—	—	1	—	1	—	1	—	2	—	—	—	—	1	—	—	—	—	1...	7
Sept. ...	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2	—	—	—	—...	4
Oct.......	—	—	—	—	1	—	—	—	—	2	—	—	—	—	1	—	1	—	—	—	2	—	1	—...	8
Nov. ...	2	—	1	—	—	—	—	—	—	2	—	—	—	—	—	1	—	—	—	3	—	—	1	—...	10
Dec. ...	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—...	2
Total..	5	—	3	3	4	3	3	3	4	9	1	3	2	5	6	4	4	2	3	8	5	5	3	5...	93

We see from the above that the maximum frequency was between 9—10 a.m. and no earthquake between 1—2 a.m.

14.—Intensity of Earthquakes.

Of the 95 earthquakes which took place in the year 1890, we will describe the most notable :—

Date.	Time of Occurrence.	Duration.	Horizontal Motion. Max. range in m.m.	Max. Vel. per Sec. in m.m.	Max. Accel. per Sec. in m.m.	Vertical Motion. Max. Amplitude in m.m.
April	h. m. s.	m. s.				
16th	9 30 47 p.m.	7 0	22.4 in 2.9 sec.	24.3	52.7	0.2 in 0 6 sec.
17th	4 56 45 a.m.	8 0	7.8 in 3.8 sec.	6.4	10.5	little
	6 42 26 a.m.	6 30	3.3 in 3.4 sec.	3.0	5.4	—
Jan. 7th	3 43 25 p.m.	5 0	2.0 in 3 sec.	2.9	6.6	—
April 17th	10 25 15 p.m.	3 30	1.2 in 2.5 sec.	1.5	3.7	—
May 15th	2 36 9 p.m.	5 30	0.9 in 2.2 sec.	1.3	3.8	—

From the above it is seen that the most severe earthquake during the year occurred at 9h. 34′ 47″ p.m. on April 16th, and had a range 22.4 mm. The origin of this earthquake must have been somewhere in Shimoda in the province of Idsu and Miyakeshima. In the neighbourhood around these localities roads were destroyed, rents were made in the ground, articles fell down or were knocked over, pendulum clocks were stopped, &c. The next shocks were those which occurred on April 17th. During the day there were three. They probably had the same origin as the one preceding them. The earthquake of January 7th took its origin somewhere in Shinano. Kami Mizuuchi, Higashi Chikuma, Kita Akumo and and Sarakumi, were most severely shaken and suffered much damage. The earthquake of May 15th had its origin somewhere in Shimoda, Izu. This district was severely affected, but no damage was done. Among other earthquakes the shocks of long duratiou were those which occurred at 4h. 56′ 45″ a.m.; on April 17th, at 9h. 34′ 47″ p.m.; on April 16th, at 6h. 42′ 36″ a.m.; on April 17th, at 2h. 36′ 9″ p.m.; on May 15th, at 3h. 43′ 25″ p.m.; on January 7th, each having a duration of 8′, 7′, 6′ 30″, 5′ 30″, and 5′ respectively. All the remaining shocks had a duration of less than 4 minutes. There was only

one earthquake which had a range greater than 20 mm., no earthquakes had a range greater than 10 mm., 4 earthquakes which had ranges, 1 to 10 mm., 28 were less than 1 mm., and the remaining 60 were so feeble that measurement was impossible.

From the preceding facts we may conclude that severe earthquakes were few in number, about 90 per cent. of them being feeble.

15.—Direction of Earthquakes.

The principal direction of motion of the 93 earthquakes this year were as follows:—

Year:	S. to N.	S.S.W. to N.N.E.	S.W. to N.E.	W.S.W. to E.N.E.	E. to W.	E.S.E. to W.N.W.	S.E. to N.W.	S.S.E. to N.N.W.	Unknown.
1890	8	1	5	1	17	3	13	—	45

Earthquake motion was therefore chiefly E.W., and after that S.E. to N.W. They occurred least in the directions S.S.W. to N.N.E., and W.S.W. to E.N.E., the next being S.S.E. to N.N.W.

16.—Nature of Earthquakes.

An earthquake may have a horizontal or vertical motion; and the motion may be rapid or slow. In the following table we show the nature of the earthquakes in 1890:—

Nature. Months.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Conbination of horizontal and vertical motion............	—	—	—	2	—	—	1	—	—	—	1	—	 5
Horizontal motion ...	2	2	2	3	5	1	3	2	4	2	1	1	28
Unknown	3	3	4	10	9	3	8	5	—	6	8	1	60
Rapid	—	1	1	—	2	1	3	1	1	4	2	1	17
Slow	3	1	—	5	5	2	3	1	3	2	4	—	29
Unknown	2	3	5	10	7	2	6	5	—	2	4	1	47

Thus of 93 earthquakes, 28 were horizontal, 5 were combination of horizontal and vertical, and 60 were not definite, being very feeble. The number of slow earthquakes exceeded that of rapid ones by 12, while 47 were so feeble that it was difficult to determine their period of vibration.

We see from the above that the maximum frequency was between 9—10 a.m. and no earthquake between 1—2 a.m.

14.—Intensity of Earthquakes.

Of the 95 earthquakes which took place in the year 1890, we will describe the most notable :—

Date.	Time of Occurrence.	Duration.	Horizontal Motion. Max. range in m.m.	Horizontal Motion. Max. Vel. per Sec. in m.m.	Horizontal Motion. Max. Accel. per Sec. in m.m.	Vertical Motion. Max. Amplitude in m.m.
April	h. m. s.	m. s.				
16th	9 30 47 p.m.	7 0	22.4 in 2.9 sec.	24.3	52.7	0.2 in 0 6 sec.
17th	4 56 45 a.m.	8 0	7.8 in 3.8 sec.	6.4	10.5	little
	6 42 26 a.m.	6 30	3.3 in 3.4 sec.	3.0	5.4	—
Jan.						
7th	3 43 25 p.m.	5 0	2.0 in 3 sec.	2.9	6.6	—
April						
17th	10 25 15 p.m.	3 30	1.2 in 2.5 sec.	1.5	3.7	—
May						
15th	2 36 9 p.m.	5 30	0.9 in 2.2 sec.	1.3	3.8	—

From the above it is seen that the most severe earthquake during the year occurred at 9h. 34′ 47″ p.m. on April 16th, and had a range 22.4 mm. The origin of this earthquake must have been somewhere in Shimoda in the province of Idsu and Miyakeshima. In the neighbourhood around these localities roads were destroyed, rents were made in the ground, articles fell down or were knocked over, pendulum clocks were stopped, &c. The next shocks were those which occurred on April 17th. During the day there were three. They probably had the same origin as the one preceding them. The earthquake of January 7th took its origin somewhere in Shinano. Kami Mizuuchi, Higashi Chikuma, Kita Akumo and and Sarakumi, were most severely shaken and suffered much damage. The earthquake of May 15th had its origin somewhere in Shimoda, Izu. This district was severely affected, but no damage was done. Among other earthquakes the shocks of long duratiou were those which occurred at 4h. 56′ 45″ a.m.; on April 17th, at 9h. 34′ 47″ p.m.; on April 16th, at 6h. 42′ 36″ a.m.; on April 17th, at 2h. 36′ 9″ p.m.; on May 15th, at 3h. 43′ 25″ p.m.; on January 7th, each having a duration of 8′, 7′, 6′ 30″, 5′ 30″, and 5′ respectively. All the remaining shocks had a duration of less than 4 minutes. There was only

one earthquake which had a range greater than 20 mm., no earthquakes had a range greater than 10 mm., 4 earthquakes which had ranges, 1 to 10 mm., 28 were less than 1 mm., and the remaining 60 were so feeble that measurement was impossible.

From the preceding facts we may conclude that severe earthquakes were few in number, about 90 per cent. of them being feeble.

15.—Direction of Earthquakes.

The principal direction of motion of the 93 earthquakes this year were as follows :—

Year:	S. to N.	S.S.W. to N.N.E.	S.W. to N.E.	W.S.W. to E.N.E.	E. to W.	E.S.E. to W.N.W.	S.E. to N.W.	S.S.E. to N.N.W.	Unknown.
1890	8	1	5	1	17	3	13	—	45

Earthquake motion was therefore chiefly E.W., and after that S.E. to N.W. They occurred least in the directions S.S.W. to N.N.E., and W.S.W. to E.N.E., the next being S.S.E. to N.N.W.

16.—Nature of Earthquakes.

An earthquake may have a horizontal or vertical motion; and the motion may be rapid or slow. In the following table we show the nature of the earthquakes in 1890 :—

Nature. Months.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Conbination of horizontal and vertical motion............	—	—	—	2	—	—	1	—	—	—	1	—	 5
Horizontal motion ...	2	2	2	3	5	1	3	2	4	2	1	1	28
Unknown	3	3	4	10	9	3	8	5	—	6	8	1	60
Rapid	—	1	1	—	2	1	3	1	1	4	2	1	17
Slow	3	1	—	5	5	2	3	1	3	2	4	—	29
Unknown	2	3	5	10	7	2	6	5	—	2	4	1	47

Thus of 93 earthquakes, 28 were horizontal, 5 were combination of horizontal and vertical, and 60 were not definite, being very feeble. The number of slow earthquakes exceeded that of rapid ones by 12, while 47 were so feeble that it was difficult to determine their period of vibration.

ON THE OVERTURNING AND FRACTURING OF BRICK AND OTHER COLUMNS BY HORIZONTALLY APPLIED MOTION.

BY

JOHN MILNE, F.R.S.,
IMPERIAL UNIVERSITY OF JAPAN, TOKIO,

AND

F. OMORI, (Rigakushi),
IMPERIAL UNIVERSITY OF JAPAN, TOKIO.

The following paper gives an account of a series of experiments carried out with the object of determining the accelerations necessary to overturn or fracture columns of various descriptions standing freely, or fixed upon a truck which was moved horizontally back and forth through a small range of motion. As the object of these experiments was to furnish those who have to build in *earthquake countries* with data respecting the quantity of motion certain forms of structure might be expected to withstand, the range of back and forth motion employed was from a half to four inches,—quantities which are comparable with the greatest extent of earthquake movement of which we have any sure measurements.

As examples of such records we quote the following:—

1.—For the Neapolitan Earthquake of 1857 from observation on cracks in buildings and other phenomena, Mr. Mallet estimated amplitudes of motion of from 2.5 to 4.7 inches. From projection phenomena and the dimensions of bodies which were overturned, the same investigation determined maximum velocities, the average of which may be taken at 12 feet per second. The fact that these data lead to the conclusion

that the period of a wave would be about 0,125 seconds, whereas we know from observations in Japan that period increases with amplitude, and that waves with amplitudes of even one inch have invariably a period of at least one second, we are compelled to accept Mr. Mallet's conclusions with caution. Yet until absolute measurements of earthquake motion were made in Japan Mr. Mallet's investigations respecting the amplitude and period of earthquake vibrations were by far the best to be obtained.

2.—February 22nd, 1880. On hard ground in Tokio a range of 21 millimetres was recorded. From the measurement of many earthquakes on similar ground we may safely conclude that the frequency of the vibrations did not exceed one per second. This indicates a maximum velocity of 60 mm. per sec. and a maximum acceleration of 360 mm. per sec. per. sec. A few chimneys fell, tiles were projected from the eaves of buildings, and one or two walls were slighty cracked. In Yokohama the range of horizontal motion was from 15 mm. (⅝ in.) to 50 mm. (2 in.). Many brick chimneys fell, tiles were shaken loose, some buildings were unroofed, grave stones were rotated, walls were cracked, and many bodies, like tiles, &c., and coping stones, were projected.

October 15th, 1884.—In Tokio, on *soft* ground, the greatest range of motion was 43 mm. and the period 2 seconds. This indicates a maximum velocity of 68 mm. per sec. and a maximum acceleration of 210 mm. per sec. per sec. One or two chimneys fell and a few walls were cracked.

January 15th, 1887.—The observations at three places in Tokio, the first of which is on soft ground, and the latter on moderately hard ground, were as follows:

	Range of motion in Millimetre.	Period in Seconds.	Maximum Velocity.	Maximum Acceleration.	Vertical Motion.	Period of Vertical Motion.
Hitotsu-bashi	21	2.5	26	66	1.8	0.9
Hongo	7.3	2.0	12	36	1.3	1.0
Chiri Kioku	19.2	2.3	24	64	5.5	0.8

In Tokio a few brick walls were cracked slightly.

In Yokohama, about 10 miles nearer to the origin of the disturbance where a horizontal motion of 35 mm. was recorded, many chimneys fell and buildings were shattered.

The conclusion is that when there is an *earth* movement of 18 mm. ($\frac{3}{4}$ in.) or over, the period is usually sufficiently short to result in accelerations causing destruction, and ranges of motion used in the experiments may be described as comparable with the motions that structures may have to withstand in earthquake countries.

Earthquakes have undoubtedly occurred where movements greater than four inches have been experienced, but measurements of these movements are not obtainable. Eye-witnesses testify to the fact that the ground has thrown out wave-like undulations, and buildings therefore have not simply been subjected to horizontal stresses but have been tipped and rocked. Such disturbances are, moreover, extremely rare, and even when they do occur the areas where the motions have exceeded the limits discussed in the following paper have been small.

The reasons why the effects due to the vertical component of motion have been overlooked are, first, the difficulties of experiment, and secondly the fact that in all earthquakes recorded in Japan the vertical component is invariably very small as compared with the horizontal movement. In the case of the earthquake of January 15th, 1887, just given, it will be seen that the range of motion for the vertical component is to that of the horizontal component in the ratio of 1 to 10; at the most 1 to 4, the latter being unusually large.

The only other experiments bearing on the oscillations necessary to overturn bodies of various dimensions are those given by one of the present authors in a paper on Seismic Experiments in Vol. VIII. of the Transactions of the Seismological Society.[1] These experiments, which only refer to ex-

(1) Seismic Experiments, by John Milne. Trans. Seis., Soc., Vol. VII., pp. 1-82.

ceedingly small columns of wood, are again referred to in the following papers.

Theoretical investigations, many of which are due to the Rev. Samuel Haughton, F.R.S., respecting overturning, fracturing, and projection, are given by Mr. Mallet in his classical work on the Neapolitan Earthquake[1].

The overturning and rocking of columns has been treated by Messrs. Milne,[2] Gray,[3] Perry[4] and West.[5] The effect produced by earthquakes of known dimensions in causing overturning, fracture, projection, rotation, &c., may be found by reference to the descriptions of earthquakes given in the Trans actions of the Seismological Society. Mr. Mallet and othe investigators, who worked prior to the establishment of th Seismological Society, used the destructive phenomena of earth quakes to determine the dimensions of the earthquakes. Th following experiments show how far the hypothesis then em ployed can be regarded as correct.

For assistance in carrying out the experiments, the author thanks are especially due to Mr. D. Larrieu, representative o Decauville & Co., who put at their disposal the truck and rai on which the experiments were made; Mr. K. Tatsuno, Pro fessor of Architecture, who designed and built the walls an columns; the Authorities of the Imperial College of Enginee ing, who furnished the workshop and workmen; Mr. Y. Yama gawa, who superintended and furnished the electrical ap pliances; and finally to their colleagues who from time to tim rendered valuable assistance.

The method of conducting the experiments will be under stood by reference to Fig. 1 A is a steel-framed truck with a wooden floor, measuring 3′.6″ by 2′.8″, the gauge of the rails on which it moved being 20″. The back and fort

[1] The Neapolitan Earthquake of 1857, by Robert Mallet, F.R.S., &c. 2 vol

[2] Trans. Seis. Soc. Vol. III. p. 44—48.

[3] Trans. Seis. Soc. Vol. III. p. 48—49.

[4] Trans. Seis. Soc. Vol. III. p. 103—106.

[5] Trans. Seis. Soc. Vol. VIII. p. 35—36.

movement of this was given by a connecting rod B, about 10 ft. long connected by the crank C to the shaft D, which was turned by hand, there being a large fly-wheel to insure regularity of motion. Columns or walls to be fractured were fixed upon the truck A by blocks of wood EE which were first brought together horizontally by cramps and then bolted down as shewn in plan and elevation. It will be observed that the range of motion of the truck can be altered by the slot and crank arrangement shown at C. The back and forth motion of the truck A. was recorded by means of a pencil at the end of the arm F. writing on a band of paper passing over the drum driven by the clock H. The speed of the paper was recorded by the arrangement shown at I, consisting of a small pendulum swinging across a pool of mercury and completing the circuit of a battery and an electro magnet. At each completion of the circuit, which occurred at intervals of about $\frac{1}{3}$ second, the electro magnet deflected a lever carrying a pencil resting on the paper carried by G. At J there was a second battery, electro-magnet, lever, and pencil. This circuit was closed by a key at the moment of overturning or fracturing and a mark was made on the paper opposite the particular vibration which was taking place when such result occurred.

Fig 2 represents the diagram obtained when overturning a brick standing freely on its end with its flat side facing the direction of motion. It will be seen that the back and forth motion commenced gently, the wave A being described in 1.4 seconds, this interval being determined by reference to the time scale, 27 ticks on which, corresponding to 27 swings of the pendulum, being described in 10 seconds. When B was described, which by measurement has a period of 0.71 seconds, the brick was overturned, the overturning point being shown by the tick at D in the line DE. The amplitude or half range of motion at B or C is 18.7 millimeters. On the assumption of a simple harmonic motion, calling the period T and the amplitude a, from the formula

movement of this was given by a connecting rod B, about 10 ft. long connected by the crank C to the shaft D, which was turned by hand, there being a large fly-wheel to insure regularity of motion. Columns or walls to be fractured were fixed upon the truck A by blocks of wood EE which were first brought together horizontally by cramps and then bolted down as shewn in plan and elevation. It will be observed that the range of motion of the truck can be altered by the slot and crank arrangement shown at C. The back and forth motion of the truck A. was recorded by means of a pencil at the end of the arm F. writing on a band of paper passing over the drum driven by the clock H. The speed of the paper was recorded by the arrangement shown at I, consisting of a small pendulum swinging across a pool of mercury and completing the circuit of a battery and an electro magnet. At each completion of the circuit, which occurred at intervals of about $\frac{1}{3}$ second, the electro magnet deflected a lever carrying a pencil resting on the paper carried by G. At J there was a second battery, electro-magnet, lever, and pencil. This circuit was closed by a key at the moment of overturning or fracturing and a mark was made on the paper opposite the particular vibration which was taking place when such result occurred.

Fig 2 represents the diagram obtained when overturning a brick standing freely on its end with its flat side facing the direction of motion. It will be seen that the back and forth motion commenced gently, the wave A being described in 1.4 seconds, this interval being determined by reference to the time scale, 27 ticks on which, corresponding to 27 swings of the pendulum, being described in 10 seconds. When B was described, which by measurement has a period of 0.71 seconds, the brick was overturned, the overturning point being shown by the tick at D in the line DE. The amplitude or half range of motion at B or C is 18.7 millimeters. On the assumption of a simple harmonic motion, calling the period T and the amplitude a, from the formula

$$V = \frac{2\pi a}{T}$$

the maximum velocity may be calculated. Other quantities which follow from the above are $\frac{V^2}{a}$ or maximum acceleration, $V/\frac{T}{4}$ or mean time acceleration.

Calculations Employed.

For various reasons, amongst which the following are the principal, it seems impossible to absolutely determine the quantity of motion necessary to overturn a body of given dimensions.

1.—The body may be set in motion and by rocking with a definite period and amplitude when it receives the final impulse which may determine its overthrow.

2.—Bodies like columns standing on end have a period of oscillation varying with the arc through which they rock.

3.—An earthquake seldom if ever consists of a single sudden movement, but of a series of movements which continually vary in amplitude and period.

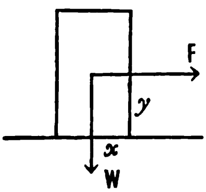
4.—Although an earthquake may consist of a series of movements which are recorded as a series of distinct waves, it often happens that such waves are accompanied by smaller superimposed waves.

The second and third reasons would lead to the conclusion that a body might be overturned by movements of exceedingly small amplitude, provided that the periods of these movements decreased at the same rate that the period of the oscillating body decreased.

Although the effects of earthquakes may be accelerated or retarded by the above mentioned phenomena, the destruction chiefly occurs with the larger movements; therefore by only considering these, although the analysis is imperfect, the results obtained are sufficiently near the truth to carry with them a practical significance.

Overturning.

Our colleague, Prof. C. D. West, treats the subject as follows:



Let M be mass of a column resting on the ground undergoing an acceleration of f feet per sec.

Let y be the height of the centre of gravity of the columns, and x the horizontal distance of the centre of gravity from the edge about which it may turn.

The inertia of the column is equivalent to a force

$$F = M f$$

The overturning moment

$$F y = M f y$$

This is opposed by the moment of the weight or

$$W x = M g x = M f y$$

whence $$f = g \frac{x}{y}$$

If f exceeds this value the column *may* go over, if less it *may* stand.

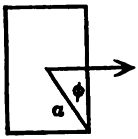
If the column is practically at rest when it receives the acceleration f it ought to fall, but if it is in a state of oscillation its fall may be hastened or retarded.

It will be shown that the quantity $g\frac{x}{y}$ which only depends on the dimensions of a body, often closely agrees with the observed quantity $\frac{V^2}{a}$ or maximum acceleration.

When V and T are small, $g\frac{x}{y}$ is nearer to the observed quantity $\frac{V}{\frac{T}{4}}$ or mean-time acceleration.

Mr. Mallet, by equating the statical work done in raising the centre of gravity of a body up to the edge over which it falls as equal to the kinetic energy of rotation, obtains the formula:—

$$v^2 = 2g \times \frac{k^2}{a} \times \frac{1 - \cos\phi}{\cos^2\phi}$$



when ϕ=the angle formed between the vertical edge of the body and the line joining its centre of gravity and the edge about which it turns

a=the distance of the centre of gravity from that edge,

k=the radius of gyration about the same edge. For solid rectangular solids $k^2=\frac{4a^2}{3}$.

g=acceleration due to gravity,

v=the velocity when suddenly applied horizontally to the centre of gravity of the body is able to bring it vertically over the edge about which the body rotates.

For a rectangular block from the above,

$$v^2=2g\frac{4\,a\,(1-\cos\phi)}{3\cos^2\phi}$$

$$\therefore \quad v=\frac{2}{\cos\phi}\sqrt{\frac{2\,g\,a}{3}(1-\cos\phi)}$$

The formula is only true on the assumption of a *sudden* impulse, whose action has practically ceased before the block has begun to move. In this case the value of the impulsive couple or moment of the impulse about the fixed edge is

$$mva\cos\phi$$

where m is the mass of the block.

The impulse, however, which acts on the block evidently depends upon the accumulated acceleration for the half period of motion to which the body is subjected.

Taking simple harmonic motion we have for displacement:—

$$x=a\sin\frac{2\pi}{T}t$$

where a = amplitude and T = period.

The acceleration is then :—

$$x''=-a\frac{4\pi^2}{T^2}\sin\frac{2\pi}{T}t$$

And the total impulse for half period is

$$I=2\int_0^{T/4} m\,x''\,dt$$

$$= m \times \frac{4\,\pi\,a}{\mathrm{T}}$$

$= m \times$ twice the maximum velocity.

Overturning Acceleration.

Here we have (1) $f = \frac{x}{y}\,g$ or (2) $f\,y = x\,g$.

If, therefore, we have a series of columns of different heights but of the same width, equation (2) gives a relation between the heights or lengths and the accelerations necessary for overturning. Supposing x constant (2) is represented by a *rectangular hyperbola* with y and f as cöordinates. The theoretical curves in Figs. 3 and 4 have been constructed from equation (2) by putting $x = 1$.

If the columns have the same height but different widths, equation (1) may be represented as a *straight line* through the origin with x and f as cöordinates.

Bodies Overturned or Fractured.

In the following list the bodies overturned or fractured are enumerated following the order in which the experiments were made. In describing the experiments classifications have been made according to the nature of the experiments.

No. of Experiments.	Nature of Bodies.	Dimensions.	Remarks.
1.	Deal Box. $\frac{1}{2}''$ wood.	$14\frac{1}{2}'' \times 10\frac{1}{2}'' \times 23\frac{1}{2}''$	On end. Flat side on. Overturned.
2.	Deal Box. $\frac{1}{2}''$ wood.	$14\frac{1}{2}'' \times 10\frac{1}{2}'' \times 23\frac{1}{2}''$	On end. Flat side on. Overturned.
3. 4. 5.	A block of wood.	$2\frac{1}{2}'' \times 6\frac{1}{2}'' \times 1'.11\frac{1}{2}''$	On end. Flat side on. Overturned.
6. 7.	Block of Pear Wood.	$11\frac{1}{2}'' \times 3\frac{7}{8}'' \times 19''$	On end. Flat side on. Overturned.
8. 9.	Block of Deal.	$2'' \times 1\frac{7}{8}'' \times 18''$	On end. Flat side on. Overturned.
10. 11.	A brick.	$9'' \times 4\frac{1}{2}'' \times 2\frac{1}{4}''$	On end. Flat side on. Overturned.
12. 13.	A brick.	$9'' \times 4\frac{1}{2}'' \times 2\frac{1}{4}''$	On end. Edge on. Overturned.
14.	One brick on edge of another.	$2\frac{1}{4}'' \times 9'' \times 9''$	On edge. Flat side on. Overturned.

No. of Experiments.	Nature of Bodies.	Dimensions.	Remarks.
15. 16.	Block of Pear Wood.	11⅛″×3⅞″×19″	On end. Flat side on. Overturned.
17. 18.	A brick.	9″×4⅛″×2¼″	On end. Flat side on. Overturned.
19.	12½ bricks as a column, mortar joints.	4″×4″×32″	On end. Broke at 2nd joint.
20.	14 bricks as a column, mortar joints.	4″×8⅛″×3.′1⅛″	On end. Flat side on. Broke at 3rd joint.
21. 22.	11 bricks as a column.	4″×8⅛″×2.′5¾″	On end. Flat side on. Broke at 2nd joint.
23.	20 bricks as a column.	4″×8⅛″×4.′4⅜″	On end. Flat side on. Broke at 2nd joint.
24.	Square brick column 23 courses.	8¾″×9″×5.′0¾″	On end. Broke at 2nd joint.
25.	Square brick column 20 courses.	8¾″×9″×4.′6⅛″	On end. Broke at 2nd brick.
26.	Square brick column 18 courses.	8¾″×9″×4.′1⅛″	On end. Broke at 2nd brick.
27.	Square brick column 16 courses.	8⅛″×9″×3.′7⅛″	On end. Broke at 5th brick—a bad joint.
28.	Square truncated pyramid, 15 courses.	5¼″x5¼″ at top 9″x9″ at bottom x3.′5¼″	On end. Broke at 2nd joint.
29.	20 bricks as a column.	4¼″×9″×4.′6¾″	On end. Edge on. Broke at 2nd joint.
30.	18 bricks as a column.	4¼″×9″×4.′1⅛″	On end. Edge on. Broke at 4th joint.
31. 32.	14 bricks as a column.	4¼×9″×3.′2⅛″	On end. Flat side on. Broke at 4th joint.
33.	Square brick column 20 courses.	9″×9″×4.′6⅛″	On end. Broke at 3rd joint.
34.	Square brick column 17 courses.	9″×9″×3.′10¾″	On end. Broke at 2nd joint.
35.	Column of cement.	2″×2″×2.′1″	On end. Did not break.
36.	Column of cement with an iron cape of 3½lbs.	2″×2″×2.′1″	On end. Did not break.
37.	Same as above with a cap of 11lbs.	2″×2″×2.′1″	On end. Did not break.
38.	A small brick pyramid.	1¼″x1¼″on top 3¼″x3¼″bottom x1.′6″	On end. Broke at 5th joint, which was bad.

No. of Experiments.	Nature of Bodies.	Dimensions.	Remarks.
39.	Concrete column. 1 part cement, 6 fine gravel.	2″×2″×22″	On end. Did not break.
40.	A block of wood.	3¾″×3¾″×12½″	On end. Overturned.
41.	A block of wood.	3¾″×4¼″×18¾″	On end. Flatside on. Overturned.
42.	Column of Cement. 1 part cement, 6 fine gravel.	2″×2″×20″	
43.	A brick.	2¼″×4¼×8½″	On end. Fladside on. Overturned.
44.	Column of cement. 1 part cement, 6 fine gravel.	2″×2″×18″	On end. Broke at end of motion by jumping of truck.
45.	A brick supported on one side.	2¼″×4¼″×8½″	On end. Flatside on. Overturned.
46.	A brick.	2¼″×4¼″×8½″	On end. Flatside on. Overturned.
47.	A brick.	2¼″×4¼″×8½″	On end. Flatside on. Overturned.
48.	Column of cement. Fine 1 part cement, 6 gravel.	2″×2″×1.′6″	Connecting rod broke, car jumped and column broke.
49.	A block of wood.	3¾″×3¾″×12½″	On end. Overturned.
50.	A block of wood.	3¾″×4¼″×18¾″	On end. Overturned.
51.	Column of cement. 1 part cement, 6 fine gravel.	4″×4″×5.′0″	On end. Broke 10″ from base.
52.	Column of cement. 1 part cement, 6 fine gravel.	4″×4″×4.′10″	On end. Broke 16″ from base.
53.	Column of cement. 1 part cement, 6 fine gravel.	4″×4″×2′	Did not break.

In addition to the above, there were 9 square columns, each 1 *sun* square and from 2 to 10 *sun* in length; also a series of cylindrical columns of similar lengths, but 1 *sun* in diameter (1 *sun*=30.3mm.) Each of these, which were made of deal, were overturned several times. The brick columns had mortar joints and were from 25 to 30 days old. The square columns were composed of courses of headers and stretchers. The concrete and cement columns were also from 25 to 30 days old.

The quantity called "West's *f*" or moment of overturning, is, however, closely related to the observed quantity V^2/a, especially for the shorter square columns. From theoretical considerations it might have been expected that the columns with relatively the smaller bases, that is the long columns, should have given results more nearly in agreement with West's *f*. The principal causestending to vitiate the experiments were :—

1. The bases of the columns may not have been absolutely flat and not accurately cut at right angles to the length of the columns.

2. The truck on which the experiments were made being designed to carry heavy weights, it had neither the smooth surface nor the even motion necessary for experimenting on columns so smooth as those which were employed.

That errors due to causes like these must have entered into the result may be inferred from the order in which the columns fell when standing together on the truck which was moving back and forth with increasing rapidity.

For cylindrical columns, one order was :—

7, 9, 6, 8, 5, 4, 3, 2.

For square columns, one order was :—

9 8 6 7 5 4 3 2

Notwithstanding the roughness of the experiments the tables show that the theoretically determined quantity called West's *f*, which depends upon the dimensions of a column, is closely connected with the maximum acceleration it experiences at the time it is overturned by a back and forth simple harmonic motion.

The same results as those given in the tables are shown graphically in the accompanying diagram.

The above results may be compared with experiments performed some years ago by one of the present authors in the

Physical Laboratory of the Imperial College of Engineering in Tokio. The details of these experiments may be found in Trans: Seis: Soc. Vol. VIII. p. 74. The results which where briefly as follows, are also represented graphically. The dimensions of the columns and amplitude of motion are given in inches, the remaining quantities being in feet.

No.	Diameter	Height	a	$V/\frac{T}{4}$	V^2/a	$f=g\frac{x}{y}$
1	1	8	1.13	4.61	7.24	4.01
2	1	6	1.38	5.64	8.85	5.36
3	1	4	1.50	6.15	9.65	8.05
4	1	3	2.25	9.23	14.49	10.7
5	1	2	2.75	11.29	17.73	16.1

Overturning of Rectangular Parallelopipeds.

	Quantities Observed.					Quantities Calculated.	West's.	Mallet's.	
No.	A	T	V	$V/\frac{T}{4}$	V^2/a	2V	$f=g\frac{x}{y}$	v	
50	18.5	.60	193	1280	2000	386	1950	382	Block like 41
49	19	.61	194	1270	1990	388	2940	330	Block like 40
47	19.5	.64	190	1190	1870	380	2600	320	A brick.
46	18.7	.71	165	924	1450	330	2600	320	A brick.
43	49	1.1	260	900	1420	520	2600	320	A brick.
41	49	1.1	284	1050	1650	568	1950	382	Block like 30
40	50	.93	340	1470	2300	680	2940	326	Block like 40

For experiments 50, 49, 47, 46 where the amplitude is small and the period short, the quantities 2V and Mallet's v are fairly comparable,

In 49 and 40, 50 and 41, 47 and 43, V varies considerably, but V^2/a does not vary to so great an extent. V^2/a is less than f the difference being sometimes as much as 30 per cent.

Overturning of Rectangular Parallelopipeds.

In the following tables *c* is half the width of a column in inches measured in the direction of the motion, and *a* is half the height, also in inches.

DIMENSIONS			QUANTITIES OBSERVED.						QUANTITIES CALCULATED.		
No.	c.	d.	a.	T.	V.	$V/\frac{T}{4}$	$V^2/_a$	2V.	West's f.	Mallet's v.	
1	5.3	11.8	81	.78	650	3320	5210	1300	4400	960	Deal Box.
3	1.3	11.8	73	2.6	230	460	722	460	1080	220	Block of wood.
4	1.3	11.8	73	1.9	241	504	790	482	—	—	
5	1.3	11.8	73	1.8	253	552	863	506	—	—	
6	2.0	9.5	74	1.3	350	1060	1670	700	2070	390	Block of wood.
7	2.0	9.5	74	1.3	370	1180	1850	740	—	—	
8	.94	9	74	1.7	274	640	1010	548	1090	182	Block of wood.
9	.94	9	73	2.0	231	460	720	462	—	—	
10	1.1	4.5	74	1.7	269	630	993	538	2400	320	A brick.
11	1.1	4.5	74	1.7	281	680	1070	562	—	—	
12	2.3	4.5	76	1.3	358	1100	1730	716	4900	680	A brick.
13	2.3	4.5	77	.78	620	3180	4990	1240	—	—	
14	1.1	4.5	73.5	1.7	279	680	1070	558	2400	320	Two bricks.
17	1.1	4.5	39	1.0	244	980	1530	488	2400	320	A brick like 10 and 11.
18	1.1	4.5	39	.85	289	1390	2100	578	—	—	
15	2.0	9.5	39	.93	265	1150	1800	530	2070	390	Block of wood like 6 and 7.
19	2.0	9.5	39	1.0	244	980	1530	488	—	—	

From the above table is will be seen that the observed quantity $V^2/_a$ or maximum acceleration in many instances is comparable with the calculated quantity f, the closest approximations to equality being, when the period of motion or T is small, and the greatest divergence when T is large. The difference between $V^2/_a$ and f is usually such that $V^2/_a > f$. Where the period T is two seconds, which is a quantity to be expected in large earthquakes, f may be 30 per cent greater than the maximum acceleration at the time of overturning.

Overturning of Columns where the Ratio of Base to Height is Constant.

The absolute dimensions of columns may possibly have effect on the values of the acceleration necessary for overturn-

ing them. To test this for ordinary columns, such as tombstones, we made the following eight sets of square wooden columns, in each of which the ratio of the base and height was the same, but the absolute dimensions were different:—

BASE. in. sq.	HEIGHT. Sun.	BASE. in. sq.	HEIGHT. Sun.
1	9	4	16
2	18	5	20
1	8	6	24
2	16	1	3
3	24	2	6
1	7	3	9
2	14	4	12
3	21	5	15
1	6	6	18
2	12	7	21
3	18	8	24
4	24	1	2.5
1	5	2	5
2	10	3	7.5
3	15	4	10
4	20	5	12.5
5	25	6	15
1	4	7	17.5
2	8	8	20
3	12	9	22.5

The blocks of the same group were put together on the truck, which was moved forward and backward either suddenly or else it was gradually worked into quick motion. It was found that almost always these blocks were practically thrown down at the same moment, so that we should think their absolute dimensions may be left out of consideration in the first approximation. From the following results, made for two different amplitudes, it will be seen that the acceleration necessary for overturning as actually observed, are generally somewhat greater than those calculated by the formula $f=\frac{x}{y}g$. The results are graphically represented in Fig. 7, in which (f) is the curve given by the latter formula, while (A) and (V) are those obtained from the average values of the maximum accelerations and velocities observed.

Overturning of Square Columns.

Number of Experiments.	Ampl. mm.	Period. sec.	Max. Vel. mm. per sec.	Max. Acc. mm. per sec.	Common ratio of base and height of blocks	$f = \frac{x}{y} g$ mm. per sec.
37	62	0.8	490	3800	1:2½	3900
38	62	0.85	460	3400	—	—
39	62	0.81	480	3700	—	—
Average			480	3600		
32	43	0.79	340	2700	1:3	3300
33	61	0.86	450	3300	—	—
34	61	0.71	540	4800	—	—
35	62	0.84	460	3500	—	—
Average			450	3600		
30	43	0.98	280	1800	1:4	2500
31	43	0.85	320	2300	—	—
1	68	1.00	430	2700	—	—
3	69	0.89	480	3400	—	—
Average			380	2600		
28	43	0.84	320	2400	1:5	2000
29	43	0.97	280	1800	—	—
5	68	0.94	450	3000	—	—
8	68	1.00	430	2700	—	—
10	68	1.20	370	2000	—	—
Average			370	2400		
26	43	1.00	270	1700	1:6	1600
27	43	0.95	290	1900	—	—
11	68	1.40	300	1400	—	—
13	68	1.10	380	2100	—	—
Average			310	1800		
24	43	1.10	250	1500	1:7	1400
25	43	0.95	280	1900	—	—
14	68	1.40	310	1400	—	—
15	68	1.20	350	1800	—	—
Average			300	1700		
22	43	1.20	230	1200	1:8	1200
23	43	1.10	240	1400	—	—
16	68	1.5	290	1200	—	—
17	68	1.4	300	1300	—	—
Average			270	1300		

20 ... 43 ... 1.3 ... 210 ... 1000 ...... 1:9 1100
21 ... 42 ... 1.1 ... 230 ... 1300 ...... — ...... —
18 ... 67 ... 1.5 ... 290 ... 1200 ...... — ...... —
19 ... 67 ... 1.5 ... 280 ... 1200 ...... — ...... —

Average............ 250 ... 1200

Overturning of Brick Columns after Fracture.

After a column by the back and forth motion* had been fractured it usually remained standing. By increasing the rapidity of motion this could be overturned, and it is to the overturning of these fractured portions to which these experiments refer.

Dimensions.			Quantities Observed.						Quantities Calculated.		
No.	c.	d.	a.	T.	V.	$V^{T}/_{4}$	$V^2/_a$	2V	Wests. l.	Mallets. v.	
23	2	24.5	12.6	.65	122	750	1180	244	797	232	Broke at 2nd joint.
24	4.3	27.7	27.3	.84	200	960	1520	400	1520	473	Broke at 2nd joint.
19	2	13.4	—	—	—	—	—	—	1460	315	Broke at 2nd joint.
20	2	14.6	—	—	—	—	—	—	1340	308	Broke at 3rd joint.
21	2	12.2	20.8	.5	260	2090	3290	520	1610	348	Broke at 2nd joint.
25	4.4	24.8	30	.69	273	1580	2480	546	1750	405	Broke at 2nd joint.
33	4.4	23.3	51	.93	343	1470	2310	686	1850	422	—
26	4.4	22.1	—	—	—	—	—	—	1950	546	Broke at 2nd joint.
27	4.4	15	30	.70	272	1550	2440	544	2880	674	Broke at 5th joint.
29	4.4	24.7	26	.58	280	1920	3020	560	1750	405	Broke at 2nd joint.
30	4.4	19.3	26	.55	298	2170	3410	596	2240	586	Broke at 4th joint.
32	2.1	13.9	—	—	—	—	—	—	1480	327	Broke at 4th joint.
34	4.5	20.7	52.5	.8	413	2070	3260	826	2130	578	Broke at 2nd joint.

In the above table the period or T is short, and Mallet's v, is in several instances fairly comparable with 2V. In Experiment 24, the maximum acceleration or V/a appears to be identica

with West's f. ; but in the remainder there is usually a wide divergence, the latter quantity being usually the smaller.

Fracturing.

For a wall or column like body, assuming that the cond ition for fracture is that the overturning moment shall be equal to the moment of cohesion of the fractured surface at the base, Mallet deduces the following formula :—

$$V = g\frac{F_0 A}{W} \times \frac{k^2}{f\beta}$$ (see. "The Neapolitan Earthquake Vol. I p 141.)

Where

V = velocity of wave path.

f = distance of centre of gravity of portion broken off from the fractured base.

F_0 = force of cohesion, or force upon unit surface which when *suddenly* applied produces fracture.

k = radius of gyration of plane of fracture about its edge.

β = thickness of the column.

W = weight of portion broken off.

g = acceleration due to gravity.

Putting $k^2 = \frac{\beta^2}{3}$ the above formula becomes :—

$$V = g\,\frac{F.\,A.\,\beta.}{3f.\,W}$$

Now if F is the force of cohesion or force upon unit surface which, when *gradually* applied, is sufficient to produce fracture, F being double F_0, the acceleration to produce fracture or α may be writen :—

$$\alpha = \frac{1}{6}\frac{g\,F\,A\,\beta}{f\,w}^{(1)} \qquad (1)$$

(1). The relation between this formula and the one employed by Mallet will be seen from the following consideration. Let the column to be fractured be regarded as a beam which is bent by its own inertia, or the impressed force $m\,\alpha$. The bending moment, or M, is therefore equal to $m\,\alpha\,f$ where f as before is equal to the height of the centre of gravity above the fractured face.

If p be the longitudinal stress at a point distant y from the neutral surface

$$p = \frac{M}{I}\,y$$

where I is the moment of inertia of the rectangular cross section with respect to the line in the neutral surface and is

$$= \frac{\beta^2}{3.4}\,A$$

If w be the weight of the unit volume of brick so that $W = 2 f A w$, then from (1)

$$a = \frac{F \beta g}{12 w f^2} \qquad (2)$$

$$\text{or } a f^2 = \frac{F \beta g}{12 w} \qquad (3)$$

Hence, if we have a series of rectangular columns of the same width, equation (2) gives a relation between the heights

---

Farther the greatest value of y in the rectangular columns experimented upon is

$$\pm \frac{\beta}{2}$$

Substituting the values for y I and M we obtain a maximum value for p, or a quantity corresponding to the co-efficient of cohesion F

$$\text{whence} \qquad F = \pm \frac{6 m a f}{A \beta}$$

$$\therefore \qquad a = \frac{A \beta F}{6 m f} = \frac{A \beta F g}{6 w f}$$

In Mallet's formula the radius of gyration is with respect to the edge of the plane of fracture, whilst in determining a, the radius of gyration is with regard to the line in the neutral surface

(2). The relationship between this formula and the formula usually employed when discussing the transverse strength of a beam supported at its ends and loaded at its centre, will be seen from the following consideration.

If l=length of beam=$2 f$

β=depth of beam in inches.

A=area of cross section of beam in sq. inches.

k=the weight required to fracture a beam 1 foot long and 1 in. sq. supported at each end and loaded in the centre.

ma_0=product of mass and acceleration causing breaking.

Since $\frac{k}{2}$ may be taken as the breaking co-efficient for the same beam fixed at one end and the weight uniformly distributed the transverse breaking force

$$ma_0 = \frac{A \beta k}{2 l}$$

$$\therefore \quad a_0 = \frac{A \beta k}{2 l m} = \frac{A \beta k g}{2 l w} = \frac{A \beta k g}{4 f w}$$

Comparing this with the above formula $a = \frac{1}{6} \frac{g y A \beta}{f w}$ and if we can assume $a = a_0$.

$$\text{then } k = \tfrac{2}{3} f$$

a, however, is the acceleration which is just sufficient to produce fracture of the beam where the stress is greatest, namely, at the concave or convex side of the beam, while a_0 is the acceleration necessary for complete cross breaking, For mortar joints a and a_0 may have values near each other, because when a part of such a point begins to break the entire joint may simultaneously give way.

The formula $a = \frac{1}{6} \frac{g F A \beta}{f w}$ used in our calculations where f is the longitudinal strength may perhaps be admissable.

of the columns (*i.e.* the heights of the portions broken off) and the accelerations necessary for fracture. Supposing β to be constant, equation (2) is represented by a cubic curve between α and f as co-ordinates. The curve is symmetrical about the axes of α (α being always positive), and it has the co-ordinate axes for asymptotes.

The theoretical curves in Figs 5 and 6 have been traced from (3) by taking proper values for F.

If the columns have the same height but different widths, then (2) gives a relation between their widths and the accelerations necessary for fracture; now if f is constant, equation (2) represents a straight line between α and β as co-ordinates. ***The fracturing acceleration is therefore simply proportional to the width or depth of the column.*** The strength of a beam is, however, proportional to the square of its depth. The reason for this difference in the cases under consideration, and probably in actual earthquakes, is that the fracturing force is assumed to be the acceleration impressed throughout the mass of the column, and not a totally external force.

PULLING STRESS.

1.—To separate 2 bricks united on flat faces = 125 lbs. = 3.67 lbs. per sq. in.

2.—To separate 2 bricks united on flat faces = 156.8 lbs. = 4.6 lbs. per sq. in.

3.—To separate 2 half bricks = 126 lbs. = 7.88 lbs. per sq. in.

4.—To separate 2 half bricks = 126 lbs. = 7.88 lbs. per sq. in.

5.—To separate 2 bricks united on flat faces = 378 lbs. = 11.1 lbs. per sq. in.

6.—To separate 4 bricks or two headers from two stretchers = 106.4 lbs. = 14.8 lbs. per sq. in.

The average for 1 and 2	= 4.1 lbs. = F'
The average for 3, 4 and 5	= 8.95 lbs. = F''
The average for 1, 2, 3, 4, and 5	= 7.03 lbs. = F'''
While 6	= 14.8 lbs. = F''''

a has been calculated for F', F'', F''' and F'''' giving values denoted by a', a'', a''' and a''''

For columns broken at a bad joint a' may apply, while for those which did not break easily, as for example No. 32, a'''' may apply.

Breaking of Brick Pyramids.

No.	β	A	g	F′	F″	F‴	F⁗	f	W	a'	a''	a'''	a''''
28	8.6	73.9	384	4.1	8.95	7.03	14.8	15.4	111	2490	5440	4270	8990

In the above, β, g and f are measured in inches.

A is measured in square inches.

F' &c. is measured in lbs. per square inch

a' &c. is measured in millimeters per sec. per sec.

By observation, fracture occurred when

$$a = 40 \text{ and } T = 0.52$$

whence $V = 480$, $V/\frac{T}{4} = 3700$ and $V^2/a = 5810$ a quantity approximating to a''

No. 38. A small brick pyramid which readily broke at a bad joint and was therefore not calculated.

Cement Columns.

No. 35. A cement column.

Here $\beta = 2$ in., $A = 4$ sq. in., $f = 10.6$ in., $W = 6.2$ lbs., $F = 400$; whence $a = 79300$ mm. per sec. per sec., the theoretical value of acceleration to cause fracture at the base.

No. 36. The same column as No. 35, but with an iron cylinder of weight $W' = 3\frac{1}{2}$ lbs. as a cap.

$$\text{Here} \qquad a = \frac{F\,A\,\beta\,g}{6f\,(W + 2\,W')}$$

$$= 38600 \text{ mm. per sec. per sec.}$$

No. 37. The same column as Nos. 35 and 36 but with a cap of 11 lbs.

Here $a = 16000$ mm. per sec. per sec. is necessary to cause fracture.

In neither of the above three cases was the column broken.

RECTANGULAR BRICK COLUMNS.

No.	a	T	V	$V/\frac{T}{4}$	V^2/a	α'	α''	α'''	α''''	A	f	B
20	46	.96	305	1280	2000	980	2000	1570	3310	34	14.6	4
19	46	.86	340	1600	2500	1030	2240	1760	3700	16	13.4	4
21	20.8	.5	260	2090	3290	1340	2930	2300	4840	34	12.2	4
22	40	.57	440	3080	4800	1340	2930	2300	4840	34	12.2	4
23	12.6	.61	130	850	1340	330	730	570	1200	34	24.5	4
24	27.3	.73	240	1320	2020	570	1240	970	2050	72.3	27.7	8.5
25	30	.62	305	1980	3110	788	1720	1350	2850	78.8	24.8	8.75
33	52	.93	350	1500	2350	888	1940	1520	3200	78.8	23.3	8.75
26	30	1.2	155	510	795	985	2150	1690	3560	78.8	22.1	8.75
27	30	.79	238	1200	1880	2130	4640	3650	7680	78.8	15	8.75
29	27	.58	291	2000	3020	791	1730	1360	2860	37.2	24.7	8.75
30	27	.52	326	2500	3920	1390	3030	2330	4910	37.2	19.3	8.75
32	59	.54	691	5120	8080	1250	2730	2150	4530	38.3	13.9	4.25
34	56	.8	440	2210	3470	1160	2540	2000	4210	80	20.7	9

The indistinctness of the record for No. 26 makes the observed quantities a and T uncertain.

Generally V^2/a and α'''' are fairly comparable.

In 26 and 27 where V^2/a is more nearly equal to α', it may be that fracture occurred at a bad joint. No. 27 certainly showed a bad joint.

The average value of V^2/a for 24, 33 and 29 is 2460, which is about double the value for 23, which is 1340.

Column 23, it will be observed, is about half the width of the other three columns. The result, therefore, tends to confirm the view that fracturing acceleration is simply proportional to the width of a column.

ILLUSTRATIONS OF THE APPLICATION OF RESULTS.

I. An earthquake with a maximum range of motion of 4 inches, and with a period of 2 seconds, would imply a maximum acceleration of about 450 mm. per. sec. per sec., a quantity very much greater than anything recorded in Tokio. As a maximum acceleration to be expected we will increase this to 1000 mm. per. sec. per sec. and determine the height to which

a brick column, two feet square, might be built above its foundation and just able to withstand this motion

Let x=height required

$\beta=2$ ft.

$A=4$ sq. feet.

$F'=5$ lbs.

$F''=15$ lbs.

w =the weight of one cubic inch of brickwork =.0608 lbs.

By substitution in the formula employed for fracturing we obtain

$$a=\frac{F\ A\ \beta\ g}{6\ f\ W}=\frac{F\ \beta\ g}{3\ x^2\ w}$$

$$\text{whence } x = \sqrt{\frac{F\ \beta\ g}{2\ a\ w}}$$

with value for F′, x=6ft. 8in.

with value for F″, x=11ft. 7in.

From the last equation, given a and β, we see that the value for x is proportional to the square root of F, or the force of cohesion.

II. As a second illustration of the application of the preceding results, we append the following discussion regarding the form which columns of given sections must have in order that they may be equally able to resist fracture when acted on by horizontal movements, at any horizontal section.

(1.) First take a column of square section. For the uniformity of strength of the column relatively to the inertia of the portion above any given horizontal section, a must be constant in the following equation

$$a=\frac{g\ F}{6}\cdot\frac{A\ \beta}{W f}=\frac{g\ F}{6\ w}\cdot\frac{A\ \beta}{V f}, \quad (1)$$

in which $W= Vw$, V being the volume and w the density.

(1) *We thank Mr. A. Inokuty of the Engineering College for having checked the following formula.*

Let x_1 = half of the dimension of any given section whose distance from the top is $= y_1$. Then

$$f = \int_0^{y_1} \frac{4\,x^2\ (y_1 - y)\ dy}{V}$$

$$\therefore\quad a = \frac{g\,F}{6\,w} \cdot \frac{4x_1^2 \cdot 2x_1}{V \displaystyle\int_0^{y_1} \frac{4x^2\,(y_1 - y)\,dy}{V}} = \frac{g\,F}{3\,w} \cdot \frac{x_1^3}{\displaystyle\int_0^{y_1} x^2 (y_1 - y)\,dy}$$

From the above equation, it can be shown that for a to be constant, there must exist between x_1 and y_1 the following relation:—

$$y_1^2 = \frac{10\,g\,F}{a\,w}\,x_1 \qquad (1)$$

which represents a parabola with its concavity turned outwards.

(2.) For a column of a circular section we have

$$a = \frac{\pi\,g\,F x_1^3}{4\,W f} = \frac{\pi\,g\,F}{4\,w}\ \frac{x_1^3}{\dfrac{V \displaystyle\int_0^{y_1} \pi x^2 (y_1 - y)\,dy}{V}} = \frac{g\,F}{4\,w}\ \frac{x_1^3}{\displaystyle\int_0^{y_1} x^2\ (y_1 - y)\ dy}$$

in which x_1 is the radius of any section. This leads to the relation:—

$$y^2 = 7\tfrac{1}{2} \cdot \frac{F\,g}{a\,w}\,x_1 \qquad (2)$$

(3.) Let the section be rectangular, and the dimension perpendicular to the direction of the motion be constant and $= b$.

$$a = \frac{g\,F}{6\,w}\ \frac{A\,\beta}{V f} = \frac{g\,F}{6\,w}\ \frac{2\,x_1\,b \cdot 2\,x_1}{\dfrac{V \displaystyle\int_0^{y_1} 2\,x\,b\,(y_1 - y)\,dy}{V}} = \frac{g\,F}{3\,w}\ \frac{x_1^2}{\displaystyle\int_0^{y_1} x (y_1 - y)\,dy}$$

From which again follows the parabolic relation:—

$$y_1^2 = \frac{4\,g\,F}{a\,w}\,x_1 \qquad (3)$$

By comparing the formulæ (1), (2), and (3), we see that with

the same given dimensions of base and height, the strongest column would be one with a square section.

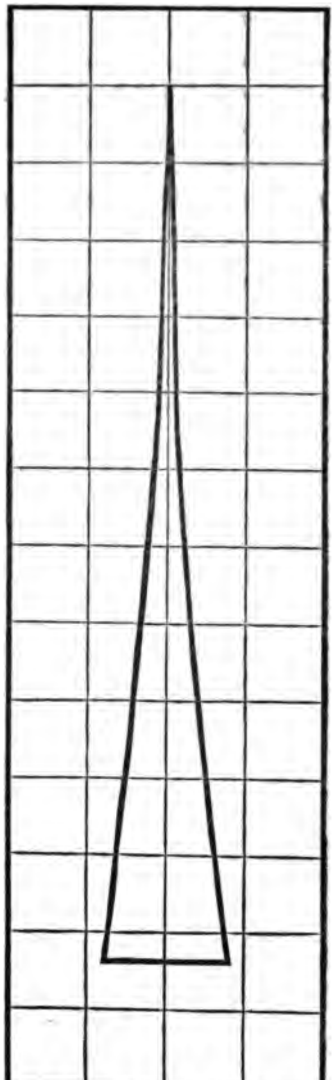
To give an illustration, suppose

$$a = 1{,}000 \text{ mm. per sec. per sec.}$$
$$F = 5 \text{ lbs. per sq. inch.}$$
$$\text{and } w = 0.0608 \text{ lbs.}$$

Then supposing the section to be square, we have

$$y^2 = 8100\,x$$

The outline of the column is as represented in the accompanying diagram.



EARTH PULSATIONS IN RELATION TO CERTAIN NATURAL PHENOMENA AND PHYSICAL INVESTIGATIONS.

BY

JOHN MILNE, F.R.S.

Imperial University of Japan.

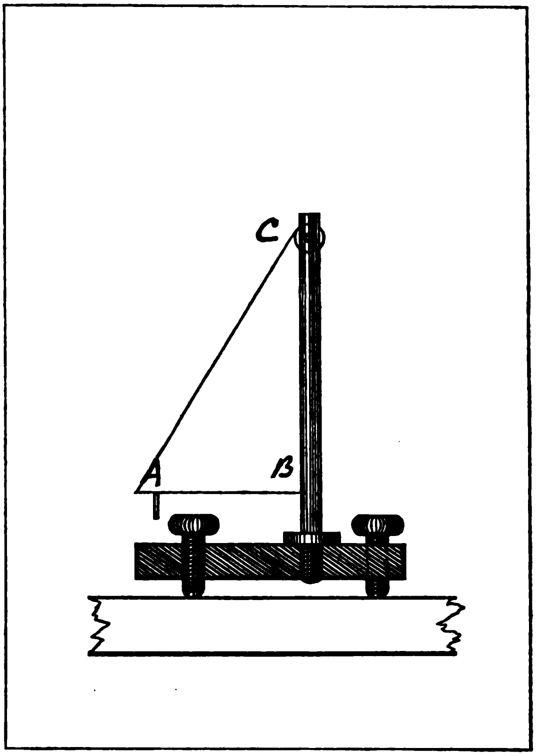
CONTENTS.

1.—RECORDING EARTH PULSATIONS — From time to time during the last sixteen years the writer has given attention to the recording of movements of the ground called Earth Tremors. From all that we know of these movements they appear to be as common in other countries as they are in Japan. The instruments employed to record them have included types of all instruments which have been used in Europe, whilst many special instruments have been designed in this country.

Amongst the former, several instruments were, in principle, identical with the mirror-pendulum arrangement employed by Messrs. G. and H. Darwin in their researches at the Cavendish Laboratory on the Lunar disturbance of Gravity. Many tromometers, like the "normal tromometer" of Bertelli and Rossi, have been used. The pendulums which were employed were usually about 3 feet in length, but also pendulums of 6 in. and even ½ in. in length, suspended in a vacuum tube have been

employed. An instrument which gave continuous records for several years consisted of a pendulum, the movements of which were magnified about 100 times by a long multiplying lever. The latter moved freely in the air, but every five minutes by means of clockwork contacts and an induction coil, sparks were discharged from its extremity, which perforated moving bands of paper. With this instrument the writer obtained records of the duration of "tremor" storms and measures of their relative intensity. All the records have been compared with the frequency of earthquakes, the state of the wind, the state of the barometer, barometric gradients, and other natural phenomena. As many of the instruments indicated changes in the vertical, for a period of nearly two years, observations were made on the movement of the bubbles of two delicate levels placed at right angles. Although every ordinary precaution was taken to avoid disturbances due to change of temperature, for several reasons it was concluded that the records were untrustworthy. One reason which is sufficient to guarantee this conclusion is the fact that when the levels were side by side and parallel, the bubble of one might creep to the left whilst the other crept towards the right. This observation is by no means original, it having been previously pointed out by M. d'Abbadie. The instrument now employed by the author to give a continuous record of tremors or tilting will readily be understood from the accompanying figure:—AB is a needle carrying at A, a mirror and kept in a horizontal positi on by the silk fibre AC. At B a needle point slightly turned downwards rests in an agate cup. The arrangement is that of an extremely light conical pendulum to which any degree of stability may be given by means of the adjusting screws. A vertical beam of light impinges on *A*, and is reflected back upon a scale, or to a horizontal slit, leading into a box where a photographic film is moving either quickly or slowly by clock work. Two of these conical pendulums with their arms at right angles reflecting light into the same box constitute a complete instrument. When the mirrors have a period of 4 or 5

seconds a deflection of the light upon the scale of 2 mm. is equivalent to a tilting of about 1 in 200,000 or 1″ of arc. Greater sensibility may be given if required.



The advantages which this type of instrument possesses over the Italian form of tromometer, and other instruments in which a more or less heavy pendulum is employed, are that in consequence of its small inertia it is not likely to show a maximum of motion when earth movements are actually small, it is more likely to give the direction of motion than can be obtained from a pendulum which has a tendency to change its plane of swing, and lastly its records are continuous and automatic.[1]

[1] At the end of this volume an epitome is given of the excellent work accomplished

2.—NATURE OF EARTH PULSATIONS.—One set of observations made in Japan which do not appear to have been made in other countries relate to the nature of the movements called earth tremors. Because the writer, at the time of a considerable barometrical depression when the place of observation was crossed by a steep barometric gradient, has observed the bubble of a delicate astronomical level every .5 to 3 seconds, pulsating through a range of from .25 to .5 mm., it was difficult to arrive at any conclusion other than that at these times the surface of the earth was being subjected to a series of minute tilts. Pronounced phenomena like these are, however, rare. What, however, is common to every so-called tremor storm, is that the spots of light from the last mentioned instruments do not swing equal distances to the right and left of a given line, nor do they commence their motion gradually.

By watching the light from two similar instruments, placed side by side and approximately *parallel*, we see that the motion of both commence *simultaneously*, *suddenly*, and in the *same direction*, giving the impression that the column had been tilted. The synchronism of motion, probably on account of the want of agreement in the natural period of the pendulums, is, however, quickly destroyed. The sudden impulses are repeated every one or two seconds, and during a tremor storm marked periods of maxima are reached every four or eight minutes.

When there are no tremors and the mirrors are caused to swing artificially, from photographic records taken on quickly running plates, it is seen that the period of swing is constant. On the contrary, when the mirrors are swinging under the influence of tremors, a similar class of records show that the period of successive waves vary within wide limits. In one experiment the periods recorded varied from 3.4 to 4.6 seconds. (See Fig. 1 in paper by Prof. Burton p. 26.)

by Dr. Reubeur-Paschwitz with an instrument of this type. Dr. Paschwitz's investigations chiefly relate to change in the vertical whilst the present writer has chiefly devoted his attention to earth pulsations. In a Report to the British Association, the writer describes his photographic method of obtaining records as new. This, however, is hardly correct, as about the same time it was being used by Dr. Paschwitz and also in Italy.

Experiment has shown that these instruments are not affected by elastic vibrations such as might be produced by a passing carriage or even by the beating of a small steam hammer stituated about 60 yards distant.

The conclusion arrived at by the author is that these movements called *earth tremors are movements in the crust of the earth not altogether unlike the swell upon an ocean.* These long flat waves, which vary in amplitude and length as they pass along, produce a tilting. Their period is from 1 to 4 or 5 seconds, and from the distance through which the light is deflected their maximum slopes may be from 1 in 40,000 to 1 in 200,000. This latter observation is, however, for the present, only given as a rough approximation and is subject to correction when the writer is provided with instruments capable of more accurate calibration.

Other observations, for example, that at times there is an apparent slow change in the vertical, that "tremors" are more pronounced in one direction than in another, that they are more frequent with a low than with a high barometer, that they are more pronounced in winter than in summer, &c., are common to Japan and Italy, and are detailed in many publications. An account of such observations may be found in the following papers by the present writer:—

1.—Observation of Tremors, &c., in the Takashima Colliery, *Japan Gazette* Jan. 12th, 1884.

2.—Earth Tremors. Trans. Seis. Soc., Vol. VII., Pt. 1. 1883.

3.—Earth Tremors in Central Japan. Trans. Seis. Soc., Vol. XI. 1887.

4.—Earth Tremors in Central Japan. Trans. Seis. Soc., Vol. XIII., Pt. 1. 1888.

5.—Earth Tremors and the Wind. Journal Royal Meteorolog. Soc., Vol. XIV., 1888.

6.—Reports upon Volcanic Phenomena in Japan to the British Association, 1881, 1883, 1884, 1885, 1887, 1888, 1892.

3.—A Possible Cause of Earth Pulsations.—In the interpretation of the meaning of the records, the conclusions

arrived at by the writer are in many respects widely different from the conclusions arrived at by many of the Italian observers. The chief differences relate to the causes which may possibly produce the movements. In Italy, tromometric disturbances which occur at the time of a low barometer are usually referred to as *baro-seismic* motions, whilst those occurring at the time of a high barometer are called *volcano-seismic*, both of which terms apparently imply a subterranean origin. M. de Rossi even suggests that the origin of the motion may be directly connected with variations in the escape of steam from a molten magna beneath the crust—the variations in activity being immediately connected with variations in external pressure. Further, he points out the connection between micro-seismic storms and earthquakes. The writer, who has carefully examined continuous records extending over several years, fails to find any connection between the time of occurrence of earthquakes and these earth movements,* whilst on the other hand there is a very close connection between these phenomena and local or distant winds ; but what the writer now recognizes of greater importance, is a still closer connection with the state of the barometric gradient. For example, the writer finds that in the Italian Peninsula tremors appear *whenever there is a steep gradient, whether the barometer is high or whether it is low.*

The same law, as shown by the following table, appears to be also true for Japan. The gradients are measured in millimeters per 120 geographical miles, this being a convenient quantity to measure on the weather charts :—

With a gradient 0, tremors were observed in 20 per cent. of the observations.

With a gradient 1, tremors were observed in 57 per cent. of the observations.

With a gradient 2, tremors were observed in 44 per cent. of the observations.

* Earthquakes and tromometric disturbances are, however, each most marked during the winter months.

With a gradient 3, tremors were observed in 50 per cent. of the observations.

With a gradient 4, tremors were observed in 88 per cent. of the observvotions.

With a gradient 5, tremors were observed in 71 per cent. of the observations.

With a gradient 6, tremors were observed in 100 per cent. of the observations.

With a gradient 7, tremors were observed in 100 per cent. of the observations.

With a gradient 9, tremors were observed in 100 per cent. of the observations.

With very high gradients it is seen that tremors have *always* occurred. With moderate gradients they have *generally* occurred. When they did not occur it may be that the gradients extended across the country in a direction or in a form unfavourable for the production or propagation of pulsatory movements. This has yet to be investigated; but it may be here stated that with gradients causing a wind from the S. or S.W. the tromometric disturbances are unusually well marked, and precede or outrace the wind by 5 or 10 hours. In the few cases where tremors were observed with a low gradient the tremors were exceedingly small, and, *in fact little more than movements that are almost at all times observable.*

Not only is there an immediate connection between a tromometric disturbance and the gradients existing at the time of its occurrence, but there is a general connection, insomuch that earth pulsations are most frequent at the seasons when barometric gradients are the steepest—which for the northern hemisphere at least, is particularly marked during the winter months. It must also be remarked that it is during these months that we have the greatest barometrical fluctuations.

If these disturbances are connected with the state of the barometric gradient, inasmuch as the effect of a gradient influences a large area, we should expect tremors to be practically

simultaneously observed over a large area, and, generally, that curves showing monthly maxima should closely follow each other over an area, for example, like Central and Western Europe. Observations show that both of these phenomena are clearly marked throughout the Italian peninsula.

As might be anticipated from the close relationship between the occurrence of these earth waves or "ground swell," and the steepness of the barometric gradient, there must also be a close relationship between earth waves and local or distant winds, and, in the author's previous work, although it was often shown that fluctuations in atmospheric pressure might be a possible cause of tremors, it was suggested that the immediate cause was the mechanical action of the wind upon the sides of mountains and other surface irregularities. Now that recent investigations have shown that earth motions are more pulsatory than tremulous, vibratory or micro-seismic, the author returns to the view first expressed in 1883 (Sec. Trans. Seis. Soc., Vol. VII. Pt. 1, p. 14), namely that these movements may be due to fluctuations in atmospheric pressure acting over considerable areas of the earth's crust, which it must be observed is of varying elasticity. That there may be deflections in the earth's crust due to barometric pressure, was shown by Prof. George Darwin in a report to the British Association in 1882 on the Lunar Disturbance of Gravity.

Assuming the superficial layers of the earth's crust to have a rigidity greater than that of glass, Prof. Darwin shows that a gradient of 50 millimeters in 1,500 miles would produce a deflection of 90 millimeters, which represents a slope of about 1 in 26 million.

With the rigidity reduced to, say one-third, which would bring this factor nearer to the rigidity of rocks as they exist on the surface of the earth, and with a steeper gradient, which is of common occurrence, the deflection would be increased.

If we imagine an elliptical area of isobars in the centre of

which the pressure is low and round its periphery high, the gradient being, say, 4 mm. per 120 miles, existing over an elastic surface, the one side of the area would be depressed and the centre raised. Let the area of isobars move at the rate of 35 miles per second, which may be taken as an average rate for a barometric depression to travel, then the rate at which the load would be changed per second at any point may be represented by about $\frac{1}{5000}$ millimetres of the mercury column. As it is probable that the earth would adjust itself to the form due to the load changing so gradually, it is not likely that at any given station whilst the depression approached and passed, anything more than a change in the vertical, first in one direction and then in another, would be observable.

Conditions of possibly greater importance are the facts that a given set of isobars do not move at a uniform rate, sometimes increasing and sometimes decreasing their relative distances, and also as is evidenced in the gusts of a storm and in the movements of a barometer, that they progress in impulses. In exceptional cases the writer has observed barometric fluctuations of .03 to .05 inches with a periodicity of from 1 to 3 seconds. Taking these latter facts in conjunction with the fact that isobars often advance in lines curving inwards or outwards, that the area over which they travel is of varying elasticity, that the rigidity of material on the surface of the earth is less than that hitherto assumed in calculations, and that the effect of suddenly applied stresses in producing deflection may be double that which would be produced by gradually applied loads, we may ask ourselves whether such conditions are likely or not likely to throw the surface of the ground into a series of flat undulations, the existence of which has apparently been experimentally demonstrated.

As to whether earth waves would outrace a depression travelling at a rate of 35 feet per second in the same manner that waves on the ocean outrace a storm, the following facts may be considered.

The Earthquake shock of October 28th, 1892, was transmitted to Tokio, a distance of about 200 miles, at a rate of about 6,000 feet per second. The resulting waves in the soft earth of Tokio were slow undulations, the length of which it was endeavoured to determine by the angle through which bracket seismographs had been tilted taken in conjunction with the records of vertical motion. For various reasons the method was unsatisfactory, and special instruments have been designed to measure such movements more accurately.

The results showed that they may have been 50 feet in length whilst their period was 1 second.

The writer has measured the speed of surface undulations produced by explosions of dynamite at less than 200 feet per second. The elastic vibrations of earthquakes have attained a velocity of about 17,000 feet per second, but usually they are very much lower, the velocity depending largely on the intensity of the initial disturbance and the medium through which it is propagated.

From the above we see that even under the worst conditions, as for example, across an alluvial plain, the waves, if produced would in every probability outrace the cause producing them.

With a steep gradient as measured atTokio there is generally a high wind somewhere in Japan, but after an examination of the weather maps it is clear that the velocity of the wind, as measured in Tokio, or as blowing in Central Japan generally, is not proportional to the gradient. Possibly, it depends upon the direction of the gradient. The extent to which wind velocity may vary will be realized from the following five examples:

1886.	Time.	Wind in Tokio.	Wind in Central Japan.	Gradient.	Direction of Gradient.
January 20th ...	9 p.m. ...	0 ...	1 or 2 ...	5.45 ...	S.E. to N.W.
January 21st ...	2 p.m. ...	3 ...	3 or 4 ...	5.21 ...	W. to E.
January 21st ...	9 p.m. ...	1 ...	2 or 3 ...	4.80 ...	W. to E.
January 22nd ...	6 a.m. ...	1 ...	2 or 3 ...	5.53 ...	W. to E.
January 22nd ...	2 p.m. ...	3 ...	3	... 3	... N.W. to S.E

Wind 0=0—1.5 m. per sec. Wind 1=1.5—3.5 m. per sec. Win:. 3=6—10 m. per sec. The gradients are in mm. per 120 geographd miles, and their direction is measured from high to low.

Mr. T. Wada, of the Meterological Bureau in Tokio, tells me that the variation of the wind with a given gradient is especially marked during the winter. He also remarks that as a centre of depression travels towards the N.E. the velocity increases at Tokio, especially when the centre is near Tokio, at which time the gradient is at a maximum.

Because tremors follow steep gradients more closely than they follow the winds, this fact may indicate that earth pulsations are more closely connected with the state of the barometric gradient, and possibly also its direction, and the form of the isobars, than they are with winds.

Another point of significance is the fact that earth waves are usually pronounced when the rate at which barometric pressure changes is rapid. For example, when the rate of change per 8 hours at Tokio is 6 or more millimeters, which usually occurs with a falling barometer, tremors are usually large—but the amplitude of the tremors does not appear to be proportional to the amount of the change.

On the possible connection between Earth Pulsations, the escape of Fire Damp, the escape of Steam from Volcanoes, and the flow of Springs.

Fire Damp.—From the writer's own experience at mines, but especially from the reports of Austrian, German, French, and English Commissions, appointed to enquire into the cause leading to the escape of fire damp, and the observations of many engineers, the relationship of fire-damp to barometical pressure and earth pulsations appears to be as follows :—

1.—The appearance of fire damp at mines *containing old workings* in which gas may accumlate is certainly very closely related to barometrical depressions.

2.—The relationship between the escape of fire-damp *from the coal* to barometrical depression, is not so clearly established. At certain mines experiments have shown that occasionally an outflow of gas is very closely related to a decrease in atmos-

pheric pressure, but usually, although there may be a fall in pressure, the escape of gas is by no means proportional to the fall, whilst it may often happen that a fall may take place and the quantity of gas issuing from the coal remains unchanged. In short, it does not appear that there is any well marked connection between the height of the barometer and quantity of gas issuing from coal; and farther, as has been remarked by other observers at mines, when gas is confined under high pressure, it is hardly reasonable to suppose that a slight variation in atmospheric pressure should produce any appreciable change in the gas which is escaping.

The writer is not aware that any observations have been made upon the escape of gas and the state of the barometric gradient. It, however, may be remarked, that when isobars are crowded together and the gradient is steep, which is during the winter months, in Germany and roughly speaking also in England, colliery explosions have been most numerous. Farther the author observes on examining the diagrams given by M. Chesneau of his experiments at Douai, that the quantity of gas was greater during the winter months than during the summer. This evidence, small as it is, suggests the idea that not only will there be found to be a seasonal connection between the escape of mine gas and the general state of the barometric gradient, but that possibly there may be a very much closer connection between the escape of gas and the state of the barometric gradient than there is with the height of the barometer. The relationship between the escape of gas and tromometric disturbances has been but little studied.

In 1883, the writer established instruments in the Takashima Colliery near Nagasaki for making such investigations, but these had barely commenced, and he had returned to Tokio, than the news arrived that everything had been destroyed by a fall of the roof.

In 1886, similar observations were made at Douai, and from the analyses of these, given by M. Chesneau, the relationship

existing between the escaping gas and earth movements is certainly more clear than it is with barometrical fluctuations. A point of some importance which the writer observes in the only detailed curves showing the relationship of tremors, the escape of gas, and barometric movements, is that on December 8th, 1886, when the former reached a maximum about 6 hours before the gas reached its maximum, and at least 20 hours before the barometer had fallen to its lowest point. As indicating a general relationship between the frequency of earth pulsations and the escape of gas, it may be mentioned that the yearly barometric curves for Italy show a close relationship with the curves showing the monthly frequency of colliery explosions in Germany.

The observations, so far as they have gone, are certainly encouraging, but to complete them the writer makes the two following suggestions.

1.—That comparisons be made between the escape of gas and the barometric *gradient* existing at the time of observation.

2.—That observations be made with a tromometer which approximately measures the steepness of the earth waves, their period, and the direction in which they advance. The objections to instruments of the pendulum type have already been stated.

Should any decided results be arrived at, then the necessity of certain mining districts obtaining information respecting barometric gradient will be as great as similar information is for our sea ports, and tromometers at many mines may be found more necessary than the barometer.

As it is likely that the relationship between earth waves and isobars may be as complicated as the relationship between isobars and the weather, we have to make our comparisons, not only with the gradient, but with the direction of gradient, the rapidity with which isobars may by travelling, their form, and generally to all those changes which meteorologists recognize as causing alterations in our weather.

Escape of Steam from Volcanic orifices and the flow of Springs.

It is often stated that there is a relationship between the escape of steam at volcanic vents and the movements of the barometrical column, and as an illustration, reference is repeatedly made to the volcano of Stromboli. From the writer's own experience at volcanic vents, although admitting that there are variations in the amount of escaping steam, he fails to recognize how a slight change in pressure, as indicated by any fall of the barometer, could cause any appreciable difference in the quantity of vapour escaping where it is under such pressure as its roaring often indicates. In cases where vapours issue gently or water escapes slowly, a barometrical fall may result in an increased volumé or flow of liquid, but in other cases it may be asked whether these fluctuations have not a closer relationship with barometric gradients and earth pulsations.

Earth pulsations, we know from experiment, to exist far below the surface, but whether by repeated compression and extension due to bending, they are capable of mechanically causing an increase in the gas of coal mines, the escape of steam from volcanoes and the flow of water from springs yet remains a subject for investigation.

Earth Pulsations and the Movements of Balances.

As an illustration of the effect of earth pulsations upon a certain class of physical instruments, the following notes are given of the writer's experiments with two delicate balances.

One balance is an assay balance by Oertling, with light arms each 100 mm. in length. The pointer is 120 mm. long and moves over an ivory scale, with divisions each 1.6mm. Facing this pointer, a microscope has been placed. The field takes in a little over one division of the ivory scale which corresponds to 6 divisions of a micrometer scale. These 6 divisions can be easily divided by the eye into quarters and approximately into tenths. The least angular displacement that could be read

would therefore correspond to a tilting of 1 in 4800. I cannot imagine the ground to be tilted to so great an angle, but I can imagine the balance receiving a succession of impulses until it was caused to swing even through greater angles.

In the Oertling balance I assume that I am able to read to a quarter of the scale divisions, which correspond to a load of $\frac{1}{100}$ of a milligramme, or the movement of a milligramme rider through half a division on the beam scale.

The second balance is a chemical balance by Bunge. The beam is 155 mm. long, and the pointer 270 mm. long.

In this balance the divisions on the ivory scale are .9 millimetres apart. With the aid of a magnifying glass I can read to half these divisions, but to obtain that movement requires the addition or subtraction of $\frac{1}{10}$ milligramme. That is to say, the rider must be moved through 5 division of the beam scale to show an appreciable alteration in the position of the pointer. Both balances stand on an exceedingly massive stone column, which for many years carried an Equatorial. Both stand east and west, the Oertling facing the only window in the room, which is usually covered with a curtain.

The following are examples of a few of the observations which have been made :—

THE OERTLING BALANCE.

A spirit lamp burning for 15 minutes in front of the glass case covering the balance produces no appreciable change. By lighting a fire and raising the temperature of the room from 62° F. to 85° F. produced the following effects :—

Time. p.m.	Temp.	Reading of Balance by Micrometer scale	and remarks.
7.30	62°	5.0	
7.35	62°	5.2	Lighted the fire.
—	82°	6.5	These positions were taken up gradually.
8.20	85°	5.0	
8.45	80°	4.8	
9.15	74°	4.2	

At the time of these observations, two mirror tromometers standing on the same column showed that tremors or tilts were very small. The balance movements may have been due to change of temperature, but they are not greater than movements which are always taking place when there is no fire. The usual range of temperature in the room is about 5°, the effect of which, even if the above experiments produced the changes indicated, may be taken as inappreciable.

One point to be noticed in the above table is that the balance took 50 minutes to complete a back and forth motion. The following are a few examples of the records which were made. They usually commenced in the morning and were continued during the day until the evening. *Bar* means the Barometer, *Bal* means balance, the records of which are the readings of the Micrometer. If two numbers are given, thus 4.2—5, this means that the pointer was moving back and forth between these numbers. Sometimes it moved out of the field and then it had to be read directly on the ivory scale. When the numbers increase it means that the zero of the pointer is being displaced to the left, and as the same effect *might* be produced by tilting the balance on its right or Eastern side, this is *for convenience* sometimes expressed by "*E. lift.*" A movement in the other direction would be "*E. sink.*" The time taken for a complete swing or period is stated in seconds. On the same column parallel to each other and side by side, are two light tromometers, also recording east and west motion. The range of pulsatory movements called *Trems*, are indicated in millimeters. As these were not automatic records, in many cases they may not represent maxima in the disturbances, as maximum motions only occur at intervals of several minutes. Displacements of the spots of light which continue for several minutes or hours, are for *convenience* called *tilts*. They are measured in millimeters and we have *E. lifted*, *E. sunk*, *E. rising*, *E. falling*. The words *balance reset*, means that the pointer having wandered out of the field, the microscrope had to be readjusted.

The barometric gradients are in millimeters per 120 miles, and are taken from the tri-daily weather maps, for 6 a.m. 2 p.m. and 10 p.m. For example, a record "S.W.-N.E. 3," means that the gradient was *from* South West *to* North East of 3 millimeters,—the barometric depression being towards the North East.

OCTOBER 7TH.

6.25 p.m, Bar. 30.1. Trems. 1. Bal. 5.5-5.75. Period 34,42 and 39—6.30. Bal. 5.8—9.00 Bar. 30.05 Bal. 5.7—5.8 Bal. reset at 4.9. Set bal. swinging—9.48. Trems. 1 bal. 6—6.1.. then 5.5—5.6—10.00 Bal. 5.8. Gradients N.E.-S.W. 3, —N.E.-S.W. 2—N.E.-S.W. 2.

OCTOBER 8TH.

8.00 a.m. Bar. 30.0 Trems. 1. East lift 1. Bal. 7—7.5., therefore east may have lifted. Reset at 4.8—8.30 Trems. 1. East sinks. Bal. 4.5 and then E. may have sunk 8.35 Bal. 5.0 E. risen. Bal. moves intermittently—11.0 Bal. 4.3 and still. 1.30 Bar. 30. Trems. 1. Bal. 4.25 and steady—9.25 Bar. 30. Trems. 1. Bal. 3.9—4.1. Set bal. swinging—10.15 Bal. 3.5—4.0. Rain and bar. falling—10.20 Bal. 3.0. E. may be sinking. Movements very slow, now and then it stops—10.25. Bal. 2.9—3 weather calm—10.30 Bal. 3.5 and it remains so for 3 minutes. Gradients N.E.-S.W. 1, E.-W. 1, and from Tokio to N. and S. 2.

OCTOBER 9TH.

7.40 a.m. Bar. 30. Trems. 5. Bal. 2.5 and steady—7.45 Bal. 2.5—3—9.28 Bal. 5—9.30 Bal. 4.5 and it keep steadily at this until 12.17 when the Bar. has fallen to 29.8. Although steady, there were apparently pulsatory tilts, say from 4.5 to 4.6 or say $\frac{1}{100}$ part of a division on the ivory scale. Weather calm but rain—12.20 Bal. 4.8—3.9—12.25 Bal. again 4.5 and steady —2.46 Bal. 4.2 and steady for 5 minutes,—9.00 Bal. 4.3 Trems. .5—9.14 Bal. 4.6—9.21 Bal. 4.8—9.30 Bal. 4.6. It seems to take about 15 minutes for a half swing.

Gradients N.W. to S.E. 2.5. N.W. to S.E. 2.5. N.W. to S.E. 1.5.

OCTOBER 10TH.

7.32 a.m. Bar. 30. Trems. 2-4. East lifted. Bal. 4.5 but in 2 minutes 2.4, one minute later 4.5, but is now moving. 4-3.8. Trems. show active tilting of East. Looking in the microscope every 2 or 3 minutes the readings run 3.5, 4.5, 4.5, 5.5, 5.3, 5, 5, and here it seems to stand as if the E. had been lifted by impulses. The weather is practically calm, there being a slight N. wind—9.40. Bar. 30. Trems. 4 Bal. 4.2-5 then 4-5. The period of these small swings is from 17 to 27 seconds—9.50. Bal. 4.6—12.18 Bar. 30. Trems. 3. Bal. 4.6. Weather calm—12.20 Bal. 4.8—12.26 Bal. 4.8—12.30 Bal. 4.6. Then these changes were made by small impulses —4.0 Trems. 2. Bal. 5.0 It has been a dull day—7.30 Bar. 30. Trems. 2—3. East lift. Bal, 5.2 but moving quickly, say from 4.2 to 5. Now and then it reaches 5.6 and 6—7.40. Bal. 5.5—6—7.42. Bal. 5.4—11.5 Bar. 30. Trems. 2-3, East lift. Bal. 2.8—6.2—11.10. Trems. 2-4. East lift 2 mm. Bal. 4.2—4.7. Now and then the Bal. stops. The tremors are large and erratic. Gradients N.W.S.E. 2.5—N.W. to S.E. 2.5. N.W. to S.E. 1.5. It must be here remarked that these gradients are about the same as on the 9th when tremors were small and the balance quiet. On both days it was generally calm in Japan, but on the 9th although there was a low barometer to the north and also to the south of Tokio; whilst on the 10th these areas of depression, and there was only one direction of gradient across the country, namely, from N.W. to S.E. Also on the 9th the isobars were nearly stationary, whilst on the 10th they were moving in the direction of their slope. That is to say although the gradients were fairly constant the atmospheric load on Central Japan was rapidly increasing. To this further reference will be made.

OCTOBER 11TH.

7.41 a.m. Bar. 30. Bal. 3-6.5 moving quickly back and forth. Trems. 2-3 and lift on east.

7.44 Bal. moves as follows 3.5-4.5. 3.5-5.5. 5.5-4.2 4.2-5.8. 5.8-4.8 &c.

7.47. Bal. inclines to settle at 4.6.

During the morning three series of readings were taken, each at intervals of 5 seconds. Keeping my eye to the microscope I gave the readings which were noted by a second observer who gave the time intervals. The results were plotted on squared paper and they are shown in the accompanying diagrams.

The gradients were W.N.W. to E.S.E. 2.5. The other two gradients were from Tokio to the N.E. and to the S.W. each about 5.

That the method of observing is fairly accurate, is testified by the manner in which in the dots indicating the observed position of the mirror, practically follow each other in a straight line whilst the balance is moving. The vertical lines represent divisions of the micrometer whilst the horizontal lines represent intervals of 25 seconds. On the original paper each of these were divided into fifths. From the diagram commencing at 8.30 we see that each half swing has differed in time and amplitude, the swings to the right having been greater and taken longer time than those to the left. The full period has varied from 50 to 35 seconds. During this time the pointer has moved from a mean position of 5.5 to a mean position of 5.7.

In the diagram taken at 9.50, the full period has varied from 45 seconds to at least 60 seconds. The increased period is apparently due to the long pauses at the end of each swing, especially when the swings are small. The amplitude has decreased, increased, and decreased. On the whole there has been a movement of the mean position from about 5 to 5.5. Both of these shifts in mean position might be explained by assuming that the eastern side of the column had been raised.

During this time the two tromometers showed move-

ments of 2 mm., and by the displacement of the light spot indicated a lift of the East of about 2 mm. At 3.25 p.m. a similar experiment was made, but as there was with but little interuption a gradual movement from 4.7 to 5.3 in an interval of 4.25 minutes, this was not plotted. At the time the tremors were about 2 mm. whilst the tilt on the East side had decreased to 1 mm. As compared with the mean position of the balance at 9.50, the balance also might indicate a change in level following the same direction.

Next the balance was *caused* to swing, the last oscillation being from 4.3 to 5.2. Eight complete swings gave a period of from 39 to 41 seconds.

It came to rest at 4.7, which is where it was when we entered the room.

These diagrams from readings of movements, the range of which are about the same as those taken when the balance has been found to be swinging, when plotted, give a regular series of curves balanced about a central line showing a practically constant period.

A number of experiments were made to see the effect of quickly opening and shutting the door of the room, walking about heavily on the floor, which is only connected with the column through the outside foundations of the building and the earth, but no effect was observable.

As the time of the above observations it was calm and the Barometer stood at 30.35.

OCTOBER 12TH.

At 8.40 a.m. a five seconds record was made of the movements of the balance, the results of which are also shown in the accompanying plate.

A large movement, it will be observed, has a period of at least 70 seconds. This motion, which might represent a sinking and then a rising of the East side of the column, is performed altogether on one side of the neutral line. Between the smaller

movements there were pauses of from 35 to 95 seconds. The neutral line appears to be about 6, that is to say, since the 11th the movement has been as if the East had been raised.

The gradients at Tokio were from N.E. 5 and to the S.W. 2.5—E. to W. 4—E. to W. 7.

It will observed that with this change in direction of a gradient, the East has been raised.

a.m. E. up.
10. ....6.8
10.5..............................6.4
12.5......30.1.......5......0......5.2......Shortly after 5-6.5 calm.
3.7......30.05 ....6.2—6.6.

OCTOBER 13TH.

Caused balance to swing and its period is from 40 to 45 secs.

Reset the balance at 4.

3.40 p.m. The barometer at 29.6 and a heavy wind. The balance is remarkably steady at 4. Now and then the tremors are steady, but now and then there are large movements of 2 to 4 mm. During the day balance slightly wanders.

5.10 p.m. Balance at 4.5. Tremors of 4 mm. and the E. sinks.

7.35. Bar. 29.6, but wind has ceased. Balance is moving from 4.8. Tremors large 5 mm. as if the E. was sinking, and the light is displaced 2 to 3 mm. Bal. goes to 4.2.

9.4. Bal. 4.2. Yet calm. Trems. generally zero, but every 3 to 7 minutes a movement of 4 mm.

9.20 Trems. show a lift on the East and balance agrees in direction. 9.30 Bal. 5.1. 10.5 Bal. 4.5. Trems. decreasing. Whilst looking in the microscope the balance moves quickly up o 3.7 and back to 4.5; with a period of 58 seconds. It was as if there had been a sink and then a rise on the E side. 10.20 Balance 3.5 to 4.5. 10.30 Balance 4—5. Neither the heat from a spirit lamp, banging the door, or stamping on the floor altered this swing.

The gradients for the day were E. to W. 7—S. to N. 5 S.W. to N.E. 2.5. That is to say, between morning and night the E.

side of Japan was relieved of pressure and therefore might rise. This generally agrees with the movement of the balance, but not with the records from the tromometers.

OCTOBER 14TH.

7.30. Bal. at 6. therefore E. has risen. Trems. 2 mm. and working back to their starting point as if the E. was rising. Fine. 11.00 Bal. 5.8. Trems. 1 mm. 2.00 Bal. 5.2 (E. sinking.) Trems. 2-4 and E. sinking. 5.00 Bal. 4.8. It is quite calm but there are Trems. of 4 mm. The gradients were S.W. to N.E. 1.5. S.W. to N.E. 1.5 W. to E. 2.

OCTOBER 15TH.

8.30. Bar. 30.05. Fine weather. Balance much disturbed, moving quickly, 5.5 to 4.5 then 4 to 4.8. 8.40 Bal. reaches 6. 12.00 Bal. at 5. Trems. 1 mm. (Since last night a sinking of 2 mm.) 5.30 Bal. 4.5 and very steady. Trems. 2 mm. and increasing, and E. sinking, which agrees with balance since the morning. 7.30 Bal. 4. Trems. 0, but E. sunk. Therefore all day there has been a sinking on E. The gradients were W. to E. 1.5 W. to E. 2.5 N.W. to S.E. 2.

OCTOBER 16TH.

9.5. Bar. 30.2. Bal. 6.2 (E. rising). Trems. 1m. (E. rising 2mm.) 1.20. Bal. 6.2. Trems. 2mm. 3.20. Bar. 30.2. Bal. 5.8. Trems. 0. 8.30. Bal. 6.8 (E. rising). Trems. now and then 1.5.-2. 8.35. Bal. 4.5 and returning quickly. Trems. 2mm. (E. lifted.) 8.38. Bal. 6.2. 9.20. Rain but calm. Bal. 8.0 (E. rising). Trems. 4m. E. lifting. From this time the movements of the balance are very erratic, the ends of swings being, 5, 6, 5.8, 6.3, 6, 6.8, 5.3, 6.4, 5,9 6.8, 6.2, 6.8, 5.7, 6.2, 5.9, 6.5, 5.7, 6.5, here it stands for 1 minute then, 6.8, 6.2, 6.5. Trems. 2mm. and E. lifted 4mm. 9.49. Bal. stands at 7 now, and then returning to 6.2. 10.00. Bal. stands at 6.5. Trems. now and then 4mm. The gradients were N. to S. 2 N. to S. 5 N.E. to S.W. 1.

OCTOBER 17TH.

7.50 a. Bar. 30.15. Fine, but rain during night. Bal. 7.

Trems. 1mm. 7.52. Bal. quickly moving 3.5 to 8 and out of field. Trems. (E. sinking). 11.40. Bal. 6.7. Trems. 1mm. 4.00. Bal. 6.2. Trems. 0. 5.52. Bal. 5.8-5.9. Trems. slight. (East lift 5mm.) The gradients were N. to S. 5, N.W. to S.E. 2, N.W. to S.E. 2.

OCTOBER 18TH.

8.8 a. Bar. 30. Dull, but calm. Bal. 6.5-6.2. Trems. steady (sink in E). 12.00. Rain, calm. Bal. 4.3 to 8. Trems. 1 to 2mm. 1.13. Bal. 3 to past 8. Period 38 to 42 seconds. Trems. 2mm. after 5 large swings for 10 minutes. Bal. remains 6 to 7. 1.35. Bal. 7. Calm and dull. 3.35. Bal. 7 to past 8 out of field. Trems. 2 to 5mm. 9.34. Bal. 5.8 to past 8. Trems. 4mm. E. lifting Bal. 3.5 to past 8. Period 39 seconds. We have here large trems. and large oscillations, calm weather and a Bar. of 30.1. The gradients were N.W. to S.E. 2, N.W. to S.E. 5 N.W. to S.E. 2.5. Without giving more observations the conclusions arrived at appear to be as follows:—

1.—The balance is nearly always moving, sometimes quickly and sometimes very slowly. When the balance is apparently quiet and it is raised on the stops and then gently lowered so that it is swings through two or three divisions of the ivory scale, its period is *about* 41 seconds. Its period when found swinging has been from 17 to 60 seconds; slower movements take anything between 1 and 50 minutes. As will be seen by reference to the diagrams and their description, the mean position of the pointer may in a short time change half a division on the micrometer scale or 1/12 division of the ivory scale. During a day it may creep through half a division of the ivory scale. The largest natural oscillations, which have been far out of the field of the microscope, have been 4 divisions of the ivory scale. These have been performed rapidly. Natural swings which vary in amplitude and period are usually performed almost entirely on one side of what for the time may be considered the mean position of the pointer. In the Oertling balance these movements are towards the left,

a result that might be obtained by raising the eastern side of the column,

The direction in motion, whether gradual or impulsive shown by the light spots from two independent tromometers agree in direction. On October 9th the balance remained steady for three hours, but this is rare. When tromometric movements are large the movements of the balance are rapid and large. Sometimes, however, the balance moves when there are no tremors, but at such a time it appears that the spots of light are being gradually displaced. This displacement may reach 3 mm. which may correspond to a tilt of 1 in 66,000.

It must be remembered that these movements have been observed in a darkened room where there is but little change in temperature, that the balance may be quiet when a wind is blowing, whilst when it is moving rapidly there may be an absolute calm, and that the movements closely follow those of the tromometers. The quick impulsive movements of tromometers I attribute to a pulsatory wave-like motion in the earth's crust, whilst the slower motions may be due to a gradual but intermittent tilting. The existence of the earth movements may be dependent on the state of the barometrical gradient, and also upon the rapidity with which atmospheric pressure is altered.

Assuming that other balances behave as mine have behaved, then the importance of paying attention to the existence or non-existence of tromometeric movements when delicate weighing operations are being carried out, as for example when making determinations respecting standard weights, is evident. Even in delicate assay work if the zero of a balance may alter within five minutes there may be times when weighing by the method of "vibrations" may be affected—the displacements referred to, being very often large enough to be measured by the eye.

2.—The Oertling and Bunge Balances.

In the second experiments, which continued over a period of

20 days, the Oertling was observed directly by the eye, while for the Bunge an ordinary hand magnifying glass standing inside the glass case was found necessary. Both balances stood on the same column in parallel positions, one facing south and the other facing north. When both balances are apparently at rest and they are caused to swing, the period of the Oertling was about 42 seconds whilst that of the Bunge was about 23 seconds. When the Oertling is swinging 3 divisions right and left, it practically comes to rest in 11 or 12 minutes. From a slightly larger swing the Bunge comes to rest in 7 minutes. In the following statement of what I observed, I shall denote the Oertling Balance as O. and the Bunge as B. :—

1.—O. showed very much more movement than B.

2.—When O. was greatly disturbed, say swinging through 1 division, B. was greatly disturbed, moving through $\frac{1}{2}$ a division.

3.—Twice I found O. moving over 4 divisions.

4.—With the assistance of my colleague, Prof. C. D. West, I have noted both balances disturbed simultaneously and in the same direction.

5.—Periods of disturbance usually occur with tromometric disturbances, but both balances sometimes move when no tremors are observable.

6.—Both balances have shown very slight but simultaneous displacements in the same direction between night and morning, —the tromometers showing displacements in the same direction.

7.—On November 4th at 8 a.m., the movements of O. were from 2 to 3.4, while B. moved from 1 to 1.5. From 11 a.m. on the same day both remained at rest until the evening of November 6th. This is the only long period when both balances practically gave constant readings.

8.—Both balances have shown considerable motion when it has been calm, the barometer high, and when the change in temperature has only been a few degrees.

9.—Both balances have remained practically at rest during a heavy gale and when the Barometer is at 29.2, as for ex-

ample, at the moment of writing, November 24th at 2 p.m.

Subsequently these balances were placed in the Balance Room of the Mining Department in the Engineering College where they stood on a massive oak shelf built in the brick wall. They were set free every morning and observed at intervals during the day. Slight changes in zero, say of .2 to 1 division of the ivory scale were continually observed, while now and then the movements were larger. On one day when as it was a holiday the buildings were empty (December 12th from 3 p.m.—4 p.m.) the swings were large, erratic and about different zeros.

Earth pulsations, Gravitation, and Astronomical Observations.

From what has been said respecting the behaviour of balances and horizontal conical pendulums, it would appear that whenever a pendulum is swung the results obtained may, amongst other things, depend upon the existence or non-existence of earth tilting and earth pulsations, which may accelerate or retard its motion, thereby altering its period and amplitude and even change its zero. In certain branches of astronomical work earth pulsations may be at least partially the cause of difficulties which hitherto have not yet been fully understood. In 1887 when Prof. Todd came to Japan in charge of an expedition to observe the eclipse of the sun, a portion of the work consisted in the endeavour to obtain photographs of the corona. To do this, the image, by means of a heliostat, was sent through a 40-foot lens before impinging on the photographic surface. From what I learn from Prof. W. K. Burton, although all parts of the apparatus were installed on solid stone columns, it appeared at times to be impossible to obtain a steady image. One cause to which this might be attributed would be to the fact that the time of observations may have coincided with a period of earth pulsations. In astronomical spectroscopic work such movements might cause considerable difficulties.

ON THE MOVEMENTS OF HORIZONTAL PENDULUMS.

AN ABSTRACT WITH NOTES ON OBSERVATIONS MADE BY DR. E. VON REBEUR-PASCHWITZ.

BY JOHN MILNE.

IMPERIAL UNIVERSITY OF JAPAN, TOKIO.

The following notes are abstracted from three papers, by Dr. E. von Rebeur-Paschwitz (see Astronomische Nachrichten Nos. 2809, 3001—02, and No. 3109—10. These papers summarize a series of observations made by Dr. Rebeur-Paschwitz in Potsdam, Wilhelmshaven, and in Teneriffe, on the movements of particularly sensitive and well constructed horizontal pendulums.

Any one of these instruments is practically identical with apparatus used in Japan to record earth pulsations, which in turn are modifications of a bracket or conical pendulum seismograph. The first instrument of this class was Zöllner's pendulum (see Kgl. Sächs. Ges. d. Wiss, 1869 and 1871). In Dr. Paschwitz's arrangement the distance between the pivots was about 74 mm. whilst the length of the frame, at the end of which there was a small weight, was about 188 mm. The frame which is made of light brass tubing, carried a mirror which reflected a beam of light from a slit to a receiving drum carrying a sheet of sensitised paper. The distance between the mirror and the drum was $4\frac{1}{2}$ metres. The pendulums were installed in the plane of the meridian, and therefore movements in a N. and S. direction were not recorded, the only movements fully recorded being

those exactly at right angles to the plane of the instrument. In Japan the writer has usually employed two such pieces of apparatus swinging in planes at right angles to each other. Every precaution was taken to isolate the apparatus from artificial disturbances, as for example change of temperature, air currents, artificially produced vibrations, &c. As in Japan, it was found that the latter disturbances only cause a slight tremor in the instrument and do not alter the position of the pendulum.

The following are a few of the results obtained in 1889:—

1.—At Wilhelmshaven the movement of the mean position of the pendulum seemed to follow barometrical changes. With a rise of the barometer the zero point moves eastward. A change of 1/4″ in the vertical corresponded to a change of 1 mm. in pressure. In fact, the pendulum, with but occasional exceptions, worked with the barometer. This, however, which may be due to the soft or marshy ground near Wilhelmshaven, was not so marked at Potsdam.

2.—A second class of movements are periodical, and apparently depend upon the position of the sun.—For example, the pendulum usually goes farthest E. about 2 p.m. and farthest W. about 4 a.m. closely following the curve for declination—the pendulum going E. when the magnet goes west. More accurately the Easterly movement is completed at Wilhelmshaven at 2 p.m. whilst at Potsdam it is at 3½ p.m. The most Westerly excursion is reached at Wilhelmshaven at 4 a.m. and at Potsdam at 8 a.m.

The Amplitude of motion at the two places is

Wilhelmshaven .... from 1.″44 to 4.″32
Potsdam .... from 0.″14 to 1.″13

It would be interesting to know if the Wilhelmshaven and Potsdam instruments were installed side by side, whether they could be calibrated with sufficient accuracy to yield indications of practically equal amounts of deflection.

In Japan the author has often had similar instruments on

the same columns in parallel positions, but although the distance of the mirror from the scale was only 3 feet, owing to the coarseness of the levelling screws and other causes he has always had difficulty with accurate calibration.

The movements in Tokio, however, appear to be as follows:—The westerly excursion of the pendulum commences about 7 or 8 p.m. and reaches a limit of as much as 5″ at about 7 a.m. At 11 a.m. it is back in its normal position and remains fairly steady until 7 p.m. Now and then there may be an easterly excursion during the day. These have been the movements recorded in January and December. On some days movements are hardly perceptible.

3.—Irregular movements are of three kinds.

a. In Wilhelmshaven especially, movements take place which remind one of magnetic storms—they are very irregular in period and in amplitude.

b. Microseismic motions which may continue for more than one day.

c. Disturbances due to earthquakes, of which 30 have been noted; some of them lasting several hours.

When considering the influence of the moon on the horizontal pendulum the most certain results that have been reached are:—

1.—At Wilhelmshaven there is a change in the vertical of 0.″28, which must be taken into account when making astronomical observations.

2.—This change cannot be entirely due to tidal load, although the observatory is near high water mark. The easterly motion of the pendulum is completed one hour before high water.

The movements may be due either to a change in level or to a deflection in the vertical, but the results are too great for the latter, therefore in Wilhelmshaven the movements are most likely due to a change in the level of the ground. At Potsdam the movements are smaller, but may be put down at 0.″01.

In his third paper Dr. Rebeur-Paschwitz adds an account of his observations in Teneriffe extending from December 26th, 1890, to April 27th, 1891. Here the instrument was not in a cellar.

The reduction constants were.

Wilhelmshaven	0."2904
Potsdam	0."2000
Puerto Orotava	0."1465

These numbers represent, in seconds, the change in the vertical for a displacement of the spot of light through 5 mm.

The movements of the instruments are equivalent to the movement of the style of a pendulum 1m. long multipled :—

3,552	times
5,156	times
7,040	times

The first discussion refers to the possible influence of the moon in producing elastic tides, which, if they have been detected, are extremely small and different at Potsdam and Teneriffe.

The daily changes observed at these places agree very closely with each other and also with the declination curve. About 9 a.m. they are farthest West and from 3 to 4 p.m. they are farthest East.

In his first paper, Dr. Rebeur-Paschwitz describes daily movements, when at 6 hours the movements are farthest S. and at 18 hours farthest North, the amplitude being 0."5.

In relation to meteorological changes Dr. Rebeur-Paschwitz observes :—1. That at all these stations a temperature effect is observable which agree with each other. 2. Atmospheric pressure acts sometimes in one direction sometimes in another, and sometimes appears to be without effect. Local conditions no doubt play an important rôle. 3. Geological conditions are connected with irregularities of movements.

In many cases the effect of strong winds confirm the observations in Tokio. The present writer, however, finds that there is a closer correspondence with steepness of barometric gradients which are not always proportional to winds.

Eight earthquake shocks have been observed near Wilhelmshaven and Potsdam, six of which were common to both places. Six were observed in Teneriffe. In eleven months 14 shocks were recorded. In Tokio sometimes six or seven disturbances not recorded by seismographs at Observatories are noted. The second class of movements may be the so-called miscroseismic motions which the present writer regarded as surface waves produced by fluctuations in barometric pressure. Three of these disturbances, however, might be the result of distant earthquakes. One of these, which is of interest to residents in Japan, is as follows:—

On April 17th, 1889, the curves at Wilhelmshaven and Potsdam were greatly disturbed (but without a sharp beginning), at 17h. 51m. and 17h. 54m. M.G.T. At 16h. 48.4m. there was an earthquake in Tokio. The distance is 9,000 km. and the difference in time 64m.3. The resultant velocity is 2.33 km. per sec.

A third class of disturbances have only been observed in Teneriffe where sometimes there are repeated movements of the pendulum without swinging. On the assumption of a velocity of 2km. then the lengths of these waves varied between 180 and 1080 km., whilst the heights from crest to sinus were between 20.5 and 83.4 mm.

As the velocity of surface waves is so variable, at times not being more than from 50 to a few hundred feet per second, although the writer has often endeavoured to give dimensions to earth waves, (see paper in this volume on Earth Pulsations in relation to various Phenomena), for the present he regards his own results as tentative. In all probability their length is nearer Dr. Rebeur-Paschwitz's minima rather than to his maxima. No doubt they vary with the soil and the intensity of

the producing cause, while they flatten, become longer, and increase in period as they radiate.

In conclusion, the writer wishes it to be understood that these notes have no pretension to be a translation of Dr. Paschwitz's work, and therefore may here and there possibly fail in accurately expressing his meaning. It is, however, hoped that they give at least an outline of what is an exceedingly valuable contribution to a certain branch of Earth Physics.

In Japan, the writer's work has been chiefly to define the nature and to study the laws governing earth pulsations (earth tremors or microseismic disturbances). Dr. Rebeur-Paschwitz has chiefly devoted his attention to changes in the vertical.

A NOTE ON OLD CHINESE EARTHQUAKES.

By F. Omori (Rigakushi).

Imperial University of Japan, Tokio.

Although China is not noted for its volcanoes, yet parts of it are subject to frequent and violent shakings. In Japan, earthquakes occur much oftener on the Pacific than on the Japan Sea side. Of the destructive ones recorded in Japan, about 57 per cent. took place on the Pacific side, 28 per cent. on the Japan sea side, and the remaining 15 per cent. in the central regions of the country. There is no peculiarity of a similar kind in the earthquake distribution of China, the activity being greater in certain interior provinces than along the coast, though near the latter we have a chain of active volcanoes extending from the Kuriles to the Philippines.

In Vol. X. of the Trans. Seis. Soc. of Japan, there is a paper on Earthquakes in China, by Dr. Macgowan. It is a great misfortune that his original catalogue of Chinese earthquakes was destroyed by fire during a riot, as such compilations are by no means easy to obtain. It is certainly difficult in this country to obtain the necessary materials, and I have succeded in collecting from histories and chronicles only those shocks which happened previous to 1644, the year of the downfall of the last Min dynasty. Altogether these amounted to 908 shocks or groups of shocks. Although nearly all of these have their precise dates given, I shall not make a statistical classification with regards to seasons, etc., as such work is not likely to give interesting results. Of these about 400 were at the capitals of the former dynasties and were probably small.

The number of earthquakes recorded increases as the time approaches the present, but, in the case of China, we must also remember that it was only since the Ghen and Min periods that the empire assumed the extent it has now-a-days. The old Chinese believed in the super-natural or moral causes of earthquakes, and the old records of earthquakes are almost invariably accompanied with notices of contemporaneous outbursts of wars, bad actions or deaths of emperors or other great personages, changes of dynasties, etc., the idea being to show that they were forerunners or consequences of some political events. In one particular instance, a severe shock occurred about the city of Chōan (now Si-ngn, Shense) on Feb. 22nd, 1128, which was then being besieged. The defenders were struck with panic, and the besiegers, profitting by the moment, captured the city.

Chōkō's seismometer, which is described in one of the old histories and illustrated in Professor John Milne's "Earthquakes," was invented in the year 132 A.D., would seem to show that the Chinese had a distinct conception of earthquake motion, particularly as to the existence of a direction of movements. Many of the shocks are described as having been preceded or accompanied by sounds. These are mostly characterized as being like thunder, and in a few cases, when weak, compared to the beating of drums. Sometimes shocks are stated as having come from certain directions.

Some of the shocks were very extensive,—covering three or four provinces, *i.e.*, about double of whole Japan. The most violent earthquake recorded in Chinese history took place on Feb. 2nd, 1556. This shook the three provinces of Shanse, Shense, and Honan, in which more than 830,000 people were killed. The meizoseismal area was a narrow zone, stretching E.-W., along the river Wei-ho (in Shensē), a tributary of the Hoang-ho, and included the south-western corner of Shense. Ground-cracks were formed and water ejected from them together with mud and fish. At some places the soil was

depressed, carrying down habitations and castles, whilst, at others it was contorted into mounds and hills, and roaring sounds were heard among the mountains. The shock was initiated by detonations like thunders, and shakings continued for many days. It will be observed that this description is similar to that of the Japan earthquake of 1891, which seems to be much smaller than the above. This great shock was not foretold by previous shocks but was followed by disturbances during the next two years. Contemporaneously with this, there was no destructive earthquake in Japan.

Examples of the meizoseismal area occupying an elongated valley tract are not uncommon. Thus, the great earthquake on September 25th, 1303, which shook the province of Shanse and destroyed some 100.000 houses, was in the valley of the river Fuen-ho, a tributary of the Hoang-ho running from north to south. Again, that of August 18th, 1561, which shook the northern portions of the provinces Kansu, Shense, and Shanse, was in the valley of the river Tsing-chooi, another tributary of the Hoang-ho running from south to north. It seems that in such cases the disturbed area was generally extended in direction perpendicular to the meizoseismal zone.

Speaking generally, earthquakes are more frequent in the provinces to the north of the Yang-tsze-kiang and in the province of Yünnan at the south-west corner of the empire. Especially the three northern provinces of Kansu, Shense, and Shanse have often been seats of extensive and violent earthquakes. Destructive ones are not uncommon, and of the 395 shocks which happened during the Min period, (1371-1644), there were 50 distinctly stated to have caused destruction of life and buildings. From this we may suppose that a destructive shock will happen on an average every 5 years in one part or other of China. These 50 shocks were distributed as follows: 17 in Kansu; 12 in Yünnan; 2 in Shense: 2 in Shanse; 2 in Szechen; 3 in Shantung; 1 in Chekiang; 1 in Kweichow; 1 in Hoope; and 1 in Shense and western Kansu; 1 in Shense,

Shanse, and Honan; 1 in Shantung, Pechili, Shanse and Shense; 1 in eastern Kansu, Shense, and southern Shanse; 1 along the coasts of the Pekin Gulf and the Yellow Sea; 4 along the coast of the Pekin Gulf. Thus a destructive shock on an average occurred, during these times, in Kansu every 16 years, and in Yünnan every 23 years. As a matter of fact, the shocks did not occur at regular intervals, but were more or less in groups. Now Kansu has been the seat of steady and comparatively uniform seismic activity, and the period seems to recur at rather regular intervals; namely, 11 shocks during the Ghen period and 28 during the Min period, which may fairly be considered as being local to the province. These were grouped as in the following table:—

KANSU.

Period.	Successive Intervals. Years.	Number of Shocks.	Intensity.
1276	34	2	3
1310	18	4	4
1328	—	5	6
(No earthquake during this interval, probably record wanting).			
1376	64	3	4
1440	36	1	2
1476	22	4	6
1498	44	3	4
1542	23	3	4
1565	33	4	6
1598	28	5	10
1626	15	4	7
1641	—	1	1
Average	32	—	—

In the above list, the "periods" were obtained by taking the means of the years of several shocks which happened within a few years of each other, and the figures representing the "intensity" by summing the corresponding intensities taken as 1 or 2 according to the degree of violence of the shocks, though probably all were severe. No such series of periods recurring after tolerably regular intervals can be observed with earthquakes in other provinces. It might be that the periods, if

existing, were too long and therefore difficult of being recognized. In the following list are given the numbers and intensities of the shocks essentially local to the three most disturbed provinces of Kansu, Shanse, and Yünnan which happened during the Ghen and Min periods, divided into half-centuries or about :—

	Kansu.		Shanse.		Yünnan.	
	Number.	Intensity.	Number.	Intensity.	Number.	Intensity.
1265-1300	2	3	11	13	0	0
1300-1333	9	10	11	13	2	3
(No earthquake during this interval, or record wanting).						
1371-1400	3	4	9	10	2	2
1400-1450	1	2	0	0	0	0
1450-1500	6	9	4	6	3	5
1500-1550	4	5	5	6	16	24
1550-1600	7	12	4	7	1	2
1600-1642	7	12	5	5	6	7

It will be seen from the above that a maximum of seismic activity occurred in Shanse in the latter part of the 13th and in the 14th, while in Yünnan it occurred in the first half of the 16th centuries. Generally there is no coincidence in times of occurrence of maxima in different parts of China, neither is there any between those in China and Japan. In the latter country, great earthquakes in its different parts sometimes occurred within a few years of each other, so that the whole of Japan may form a single seismic zone, while the northern and the south-western parts of China form distinct seismic regions. The shocks in Yünnan were mostly local. The most disturbed of the coast provinces are Pechili and Shantung, where destructive shocks have sometimes occurred. In the provinces of Chekiang, Fookien, and Kwangtung, shocks were rare, and of the 17 in these provinces which happened during the Min period none are positively stated to have caused destruction of life and buildings. The areas shaken in these cases were mostly along the coast and very rarely extended inland. Probably the origins might have existed in the Formosa Channel, Fookien has been the most frequently disturbed

province of the three. The four interior provinces of Kiangsi, Hunan, Kwangsi, and Kweichow are the least disturbed regions in China.

The city of Nankin was shaken 30 times during 70 years between 345 and 414 (Eastern-Shin period), and about 110 times during 273 years between 1372 and 1644 (Min period), so that as earthquakes happened on the average in these two epochs respectively every 2·3 and 2·5 years. If, however, we count all the shocks in the same year as forming one group, then there were in the same two epochs respectively one group of shocks every 3·5 and 7·5 years on the average. From facts like the above we cannot deduce any conclusion as to the question whether there has been any decrease in the seismic activity during these centuries. But we should be rather inclined to believe that there may have been some such decrease at Nankin, especially considering the extremely turbulent condition of the former epoch. None of these shocks seem to have been destructive, and sometimes it is particularly stated that houses moved and made cracking sounds, etc. In the year 1425, there were 42 shocks in Nankin, and 8 or 10 during each of the two following years. The city of Pekin was shaken 88 times during 237 years between 1403 and 1639, or on average there was one shock every 2·7 years. Of these 88 shocks, 12 were severe, though not destructive. The one in 1266 (Ghen period) was sufficiently strong to cause some damage to walls, while another, a few years before, caused (in the vicinity of the city) landslips in mountains and depressions of ground, and many people were killed. Probably the neighbourhood of Pekin is more largely shaken than that of Nankin. Thus there were, during 163 years between 1476 and 1638, 18 shocks around the Pekin and the Leaoton gulfs, of which 6 were destructive; while there were during 168 years between 1477 and 1644, 21 shocks about the mouth of the Yang-tsze-kiang of which only one was destructive. We append

below the numbers of shocks which occurred at some of the older capitals:—

At Rakuyo (now Honan, in Honan), 53 shocks during 103 years (92—194), and 13 shocks during 46 years (269—314).

At Chōan (now Singan, Shense), 36 shocks during 261 years (619—879).

At Rin-an (now Hangchow, Chekiang), 27 shocks during 193 years (1029—1221).

A NOTE ON THE GREAT EARTHQUAKE OF OCTOBER 28TH, 1891.

(SEE REPORT TO THE BRITISH ASSOCIATION 1892.)

BY JOHN MILNE.
IMPERIAL UNIVERSITY OF JAPAN, TOKIO.

If we may judge from the contortions produced along lines of railway, the fissuring of the ground, the destruction of hundreds of miles of huge embankments which guard the plains from river floods, the utter ruin of structures of all descriptions, the sliding down of mountain sides and the toppling over of their peaks, the compression of valleys, and other bewildering phenomena, we may confidently say that last year, on the morning of October 28, Central Japan received as terrible a shaking as has ever been recorded in the history of seismology. It is a subject that might be written about at interminable length, and therefore in the following few pages no attempt is made to give detailed descriptions of all that happened.

Mr. F. Omori, who works with me in the Seismological Laboratory, has made several visits to the shaken district, and ever since has been busily engaged in analysing the materials he collected. Professor Tanakadate, with a staff of assistants, devoted himself to observations relating to the velocity of propagation of earth-waves, the curious sound phenomena, and, lastly, to a redetermination of magnetic elements in the devastated district. Dr. B. Koto has studied the phenomena from a geological standpoint.

Under the title of "The Great Earthquake in Japan," in conjunction with Professor W. K. Burton, I have published a

popular account of the more striking phenomena which were observed, illustrating the same by a series of photographs. The questions to which greatest attention has been given are those of importance to engineers and builders, but inquiries and investigations have been made relating to everything which was thought to be of interest. A few days after the disaster, at the request of Professor D. Kikuchi, I drew up a circular containing some fifty queries. Ten thousand of these documents were issued, and we are now surrounded by boxes filled with newspaper cuttings and replies. Five per cent. of the whole may be of value, but yet it has all to be patiently examined. In addition to this material, there is that of our own collecting, which, in addition to what has already been mentioned, includes some hundreds of diagrams taken by seismographs of what seemed to be at one time an unending series of shocks which followed the great disaster. This chaotic mass of material is gradually being sifted, and assuming a form suitable for systematic investigation. Although many of the results may be more marked by the magnitude of the phenomena they represent rather than by their novelty, we have already gone sufficiently far to see that certain observations can hardly fail in widening the circle of our present knowledge.

The first notice that I received of the earthquake was at 6h. 39m. 11s. on the morning of October 28, whilst I was in bed. From the manner in which my house was creaking and the pictures swinging and flapping on the wall I knew the motion was large. My first thoughts were to see the seismographs at work; so I went to the earthquake-room, where to steady myself I leaned against the side of the stone table, and for about two minutes watched the movements of the instruments. It was clear that the heavy masses suspended as horizontal pendulums were not behaving as steady points, but that they were being tilted, first to the right, and then to the left. Horizontal displacements of the ground were not being recorded, but angles of tilting were being measured. That whenever

vertical motion is recorded there must be tilting, and therefore no form of horizontal pendulum is likely to record horizontal motion, is a view I have often expressed. What I then saw convinced me that such views were correct. Next I ran to a water-tank which is 80 feet long, 28 feet wide, and 25 feet deep. Its sides are practically vertical. At the time it was holding about 17 feet of water, which was running across its breadth, rising first on one side and then on the other to a height of about 2 feet. It splashed to a height of 4 feet. It seemed clear that the tank was being tilted, first on one side, and then on the other. Whilst this was going on, trees were swinging about, telegraph-wires were clattering together, the brickwork of the tank was cracked, and the college workshop a two storied brick building, a few yards away, was so far shattered that it has had to be partially rebuilt. The effect of the motion upon myself was to make me feel giddy and slightly sea-sick. The chimney of a paper-mill in Tokio fell, and also a chimney at the electric-light works in Yokohama. The constructor of the latter derived some satisfaction from the fact that it fell as a heap of loose brick round its base, for had it been made of better materials, it might have toppled over in large masses, and destroyed neighbouring buildings. Many structures were slightly fractured. During the day twenty-one other shocks were recorded, but nearly all of them were so slight that they failed to give a diagram sufficiently large for analysis. From the slow and easy swinging nature of the motion, it was known that the shock was not of local origin, but that it had originated at a distance. As disturbances of this character had often reached us from an area beneath the Pacific Ocean about 400 miles to the north-east, it was from the northern parts that we expected to receive further information. The surmise that the origin was at a distance proved correct, but instead of being beneath the ocean to the north-east, it was beneath the land in an exactly contrary direction. The first news was that in Kobe, which is about 400 miles towards the south, many chimneys had fallen,

earthquake shocks continued, and all were in alarm; whilst at Osaka, which is 356 miles from Tokio, a cotton-mill had collapsed and many people had lost their lives. Little by little news of destruction arrived from many towns, and as it came it grew more terrible. The scene of greatest disaster was the Nagoya-Gifu Plain, which lies about 140 miles W.S.W. of Tokio, and 80 miles N.E. of Kobe. In this district destruction had been total. Cities and villages had been shaken down, the ruins were burning, bridges had fallen, river embankments had been destroyed, the ground was fissured in all directions, and mountain sides had slipped down to dam the valleys. More accurate estimates of certain damages are now before us. The killed numbered 9,960, the wounded 19,994, and the houses which were *totally* destroyed were 128,750. In addition to these there were many temples, factories, and other buildings. In an area of 4,176 square miles, which embraces one of the most fertile plains of Japan, and where there is a population of perhaps 1,000 to the square mile, all the buildings which had not been reduced to a heap of rubbish had been badly shattered. To rebuild the railway, reconstruct bridges, roads, and embankments, and to relieve immediate distress, about five million *yen* were poured into the district, a large portion of which came from the Imperial treasury. This sum, however, only measured a fraction of the total destruction. One hundred thousand houses had to be rebuilt, irrigation works had to be repaired; a value had to be given to land which had been buried by landslides or lost by what appears to be a permanent compression of valleys; there had been a six months interruption of traffic and of industries, and nearly 10,000 people had lost their lives—all of which are factors which cannot be overlooked when measuring the effect of an earthquake by the sum it takes to replace the damage it has occasioned. Independent of the lives which were lost, the total cost of the earthquake may be recorded as thirty million *yen*.

The immediate cause of this great disburbance was apparently the formation of a fault which, according to Dr. B. Koto, can be traced on the surface of the earth for a distance of between forty and fifty miles. There are also many minor faults. In the Neo Valley, where it runs nearly N. and S., it looks like one side of a railway embankment about 20 or 30 feet in height. The fields at the bottom of this ridge were formerly level with the fields which are now on the top of it. In Mino, where it strikes towards the east, it is represented by subsidences and mound-like ridges, suggesting the idea that they might have been produced by the burrowing of a gigantic mole. Although there is only 20 feet of displacement on the surface, from what we know of surface disturbances resulting from the caving in of subterranean excavations, the maximum throw of this fault is in all probability very much greater than that which is accessible for measurement. Not only have the rice-fields been lowered, but, according to the peasants, the mountain peaks on the western side of the valley have decreased in height.

In addition to the evidence of subsidence along this line, there are many evidences of horizontal displacements. Lines of roads have been broken, and one part of them thrown to the right or left of their original direction; whilst fields which were rectangular have been cut in two, and one-half relative to the other half has been shifted as much as 18 feet up or down the valley. One result of this, is, that landowners find there has been a partial alteration in the position of their neighbours. A more serious change has been the permanent compression of ground, plots which were 48 feet in length now measuring only 30 feet in length. It appears as if the whole Neo Valley had become narrower. A similar effect is noticeable in the river-beds, where the piers of bridges are left closer together than they were at the time of their construction.

Since the big shock about 3,000 minor shakings have been recorded. At Gifu and Nagoya, where most of these were felt, their distribution with regard to time was as follows,

the numbers representing the number of shocks which were recorded during successive intervals of ten days :—

	Month.	Day.		Month.	Day.	Nagoya.	Gifu.
1891:	X	29	1891:	XI	7	559	1,132
	XI	8		XI	17	123	341
	XI	18		XI	27	76	116
	XI	28		XII	7	48	139
	XII	8		XII	17	40	190
	XII	18		XII	27	27	75
	XII	28	1892:	I	6	36	87
1892:	I	7		I	16	9	60
	I	17		I	26	6	36
	I	27		II	5	9	45
	II	6		II	15	7	37
	II	16		II	25	11	39
	II	26		III	6	9	40
	III	7		III	16	3	28
	III	17		III	26	3	13
	III	27		IV	5	9	42
	IV	6		IV	15	1	26
	IV	16		IV	25	4	28
				Total	—	980	2,474

The most violent shakings took place high up in the Neo Valley, on the line of the great fault, and again in a district to the west of Nagoya, about 25 miles farther south, in the middle of the Owari Plain. This second area of great disturbance may indicate the proximity of a second line of fracture not visible on the surface, or it may be an area where waves from various sides of the plane coalesced.

With the first of these shakings, great landslips took place, and long lines of mountains which were green with forest now look as if they had been painted yellowish white. The valleys in these districts have been filled with débris, and behind one of the dams which has been formed there is now a lake six miles in circumference. In one district on the eastern side of the plain we are told that mountain peaks fell in and depressions were formed. Depressions also occurred in some of the valleys, and the houses of farmers suddenly sank up to their eaves, burying their inmates in a sea of earth and mud beneath the floor on which once they lived.

In the plains, river embankments which on the top are from 20 to 30 feet in width, and have slopes of 3 to 1 and 2 to 1, were very much cracked and fissured. Usually these cracks were 2 or 3 feet in width, but in places they had so far united that openings 10 or 15 feet wide and about the same in depth had been formed. In all cases the fissures were parallel to the river bank, and it was in villages near these banks where destruction had been most complete. It might be expected that these fissures would occur at distances of half wave-lengths from the river bank, and at similar distances from each other, but no such rule was observable. The general appearance of the ground was as if gigantic ploughs, each cutting a trench from 3 to 12 feet deep, had been dragged up and down the river banks.

Fissures, out of which sand and water had been poured, sometimes to form small craters, were also to be seen on the open plains. These fissures, which seldom exceeded a foot in width, and which may have been formed by the compression of watery strata beneath, may possibly give approximate measures of maximum horizontal displacement, it being assumed that the direction of motion was at right angles to the direction of the fissure.

Along the railway-line many curious appearances were presented. It was almost everywhere more or less disturbed, the exceptions being where it passed through small cuttings. Along these cuttings, although they might not be more than 20 or 50 feet in depth, the rails and sleepers were unmoved; from which it may be inferred that the movement on the free surface of the plain had been much greater than the movement at a comparatively shallow depth. Measurements of the motion experienced on the surface and that recorded in pits 10 to 20 feet in depth have already been given in former papers. The results of these experiments have been practically applied to several buildings in Tokio, by giving them basements and a free area. The Imperial College of Engineering

is such a building. It does not show the slightest trace of damage after the last earthquake, whilst at a distance of 20 yards the workshop, which is also a strong brick building, but rising from the surface, as already stated, has been rebuilt. This is the third time the Engineering College has escaped damage, whilst neighbouring brick buildings have been cracked in almost every room.

Where the line was on the open plain, and only separated from it by a narrow ditch on either side, it appeared as if the ground had been piled up into bolster-like ridges between the sleepers. This indicated a longitudinal motion, but in many places it was noticeable that the sleepers, relatively to the ground, had also been moved endways. Neither of these movements greatly exceeded 6 inches. Wherever the line crossed a small depression in the general level of the plain, even if it did not exceed 2 or 3 feet, at such places the whole of the track was bent from its straight course into a bow-like form, suggesting the idea that along these depressions, which are probably filled with softer material than that composing the plain, a greater quantity of motion had been transmitted, which, striking the line like a flood, had caused a permanent deflection. The more reasonable explanation is that these lines of soft material, like the valleys and river-beds, had been permanently compressed, and the amount of compression was measured by the amount of bending. Effects of compression were most marked on some of the embankments, which gradually raise the line to the level of the bridges. On some of these, the track was bent in and out until it resembled a serpent wriggling up a slope. Not only were there these horizontal foldings, but by subsidence or compression there were vertical folds, which in places gave the line the appearance of a switchback. Close to the bridges the embankments had generally disappeared, and the rails and sleepers were hanging in the air in huge catenaries.

At the bridges, one of which, over the Kisogawa, made

up of 200-feet spans, is 1,800 feet in length, the destruction was various. In nearly all cases wing walls had given way. At one brick bridge the abutments had been forced backwards, and the arch had fallen bodily between them down upon the roadway, where it lay in two big segments, looking like a gigantic toggle-joint. At the Nagara Bridge the piers, each of which consisted of five large iron columns filled with concrete and braced together, had in several instances not simply been broken at their bases, but they were snapped in pieces and thrown out upon the shingle beach of the river, where they lay like bits of broken carrot. The bridge was thrown 19 feet out of a straight line, and one of the foundations near the centre of the river had been mŏved 5 feet 2 inches up-stream. Where the greatest deflections occurred the foundations could not be positively recognised.

Mr. C. A. W. Pownall, who constructed these bridges, and who gave me the above measurements, estimates the deflection on the line where it approaches the bridges at 1 foot 6 inches in a distance of 90 feet. The distance through which the foundations of the Kiso Bridge have permanently approached each other is 2 feet in a span of 200 feet—that is to say, the contraction across the river-bed is 1 per cent. When all the piers of a bridge had not been broken, it was observed that those which escaped were the shorter ones, near the river banks. The longer piers of the Kisogawa Bridge had a cross-section of 22·5 feet by 10 feet, and a height of 29 feet above the plane of fracture, which was 4 or 5 feet above their foundations. They carried girders weighing about 200 tons. The shorter piers, which also had a cross-section of 22·5 feet by 10 feet, had heights of about 21 feet above their planes of fracture. They carried girders weighing about 22 tons.

The tensile strength of the brick and cement work of these piers was, as shown by tests made by the writer, unusually high, often reaching 100lb. to the square inch. When making these tests, it was seldom that the cement gave way, fracture

taking place either by the breaking of the brick or by *separation* between the cement and brick,

The tensile strength of brick and mortar work from cotton-factories and other private buildings seldom exceeded 5lb. to the square inch.

Professor Tanabe, of the Imperial College of Engineering, has very kindly applied the fracturing formula to the Kisogawa and other structures, with the following results:—

The tall piers at the Kisogawa Bridge, which were broken, were capable of resisting an acceleration of 5.05 feet per sec., whilst the shorter piers, which were also broken, could have resisted a force involving an acceleration of 10.8 per sec. per sec.

The acceleration in the neighbourhood of this bridge was therefore greater than the higher of these two numbers. Because there is no necessity that one set of piers out of a series should only have half the strength of another group in the same series, or that any given structure should be weaker at its base than it is in its upper parts, so far as resistance to stresses consequent on horizontal movement is concerned, the writer ventures to express the opinion that when constructing in an earthquake country, ordinary engineering practice requires modification. Such modifications are being made by Mr. C. A. W. Pownall in the design of a series of bridges now being built up the Usui Pass, in this country.

For the Nagara Bridge, where cast-iron piers have snapped in two, the accelerations experienced have not yet been calculated.

Leaving the railway works, and examining the various brick-and mortar structures, like public buildings and mills, which existed at many towns upon the plain, we meet with hardly anything but absolute ruin. Two conspicuous brick-and-mortar ruins in Nagoya were the Post Office and a cotton-mill. Walls like these, even if not weakened by openings near their base, assuming them to have been 40 feet high and 1½ foot thick, and with a tensile strength for their brickwork of 5lb.

per square inch—which is not an underestimate—might have resisted a suddenness of motion of a few inches per sec. per sec. From overturning phenomena and diagrams we know the acceleration impressed upon buildings in this area may have been as much as 15 feet per sec. per sec.

One curious form of destruction was that which was observed with many mill chimneys, which, with the exception of one in Yokohama, instead of breaking at their bases, gave way at about two-thirds their height. The conclusion is, that sections near the bases of these chimneys were apparently sufficiently strong to resist the stresses due to the inertia of the upper parts, while sections at about two-thirds the height were so weak that they failed to resist the inertia effect of the upper one-third of the chimney. Calculations respecting these structures have not yet been made.

The ruins of ordinary Japanese buildings existed along all the roads in never-ending lines. In some streets it appeared as if the houses had been pushed down from the end, and they had fallen like a row of cards. Where a row of buildings had only been partially pushed over, it was noticeable that those at the end had suffered more than their neighbours. Sometimes you passed a mass of heaped-up rubbish, where sticks and earth and tiles were so thoroughly mixed that traces of streets or indications of building had been entirely lost.

Many of the ruined towns, like Kasamatsu and Gifu, caught fire, and all that remained was a sea of reddish earth and broken tiles. At several places people were caught in the fallen ruins, and subsequently burnt to death. The chief causes which led to the destruction of Japanese buildings were:—

1. The heavy roofs, which are usually made of a heavy framework carrying a layer of heavy tiles bedded in a thick layer of mud. The roofs of the farmers' houses are covered with a heavy thatch. These latter fell intact, and even now the country is covered with these saddle-shaped masses, which have served as temporary tent-like shelters.

2. The want of cross-bracing and the thinness of the vertical supports, the strength of which, as pointed out by Mr. W. Silver Hall, is reduced to perhaps an eighth of what it might be, by a variety of tenons, mortices, and other cuts, made for the reception of cross-timbers.

Both of these faults in the construction of an ordinary Japanese dwelling might be easily overcome, but from the buildings which are now being erected it is clear that the survivors prefer that to which they have been accustomed and can easily obtain. Buildings to resist earthquake motion are outside the experience of ordinary carpenters in Japan, and any novelty in construction would be expensive. For these reasons, and perhaps with the idea that severe earthquakes only recur at long intervals, the inhabitants of the Nagoya district are giving another trial to the old forms of construction.

Among the buildings which were only shattered, but which did not fall, are two castles and several heavy-roofed temples.

The castles stood, partly perhaps, because they were well built, partly because they were surrounded by deep moats, but chiefly on account of their pyramidal form, their bases being sufficiently wide and strong to withstand effects due to the inertia of their upper parts.

The temples undoubtedly resisted the severe movements partly because they were well built, but chiefly, perhaps, on account of the multiplicity of jointed corbel-work, which comes between the upper parts of the supporting pillars and the heavy roof. If this had not existed and acted as a yielding medium between the roof and its supports, it seems impossible that the latter could have resisted the inertia of the load above them.

A class of buildings which here and there escaped entire destruction were structures like some of the school-houses, which were built of wood, and framed according to foreign methods.

The movements which caused all this terrible destruction throughout the Gifu and Nagoya Plain do not appear to have

been waves which were entirely those of elastic compression and distortion. On the coast-line to the north of the devastated district we are told that the shore-line rose and fell, and with this rising and falling the waters receded and advanced. In the district itself many eye-witnesses tell us that they saw the ground in waves.

Mr. Kildoyle, an engineer, who at the time of the disaster was in Akasaka, says that the waves came down the street in lines. Their height may have been 1 foot, and the distance from crest to crest anything between 10 and 30 feet; but he very naturally added that he could not be sure of any measurements, as he was expecting that the houses on one side or the other of the street might at any moment fall in upon him. It may here be remarked that because on the street side of the houses in a town there are many openings, which make this side of the buildings weaker than they are at the back, the tendency is to fall forwards from two sides into the street. For the safety of the inhabitants of a town, special attention ought to be given to the construction of shop and other frontages, and the streets be made wide.

Another indication of wave movement is the statement of people who say that after they had been thrown upon the ground the movements of the earth rolled them from side to side. A station-master, who tumbled on the ground as the station-house fell close behind him, showed the writer the manner in which he seized one of the rails whilst lying on the ground, the rail passing between his legs. While in this position he was tumbled from side to side, first striking the ground with one shoulder, and then with the other.

Reasons for believing that in Tokio the ground was thrown into long undulations have already been given. First, there was the evidence of our sensations; secondly, the observation of the manner in which water moved in ponds; and, thirdly, the observations on the movements of bracket seismographs, which were tipped from side to side. The most certain evidence

about the tilting is, however, that which is furnished by the diagrams of many seismographs, which, rather than showing a series of irregular waves with superimposed irregularities, in almost all cases show a series of clean-cut curves. In one instrument which was tested, the periodicity of these curves did not agree with the period of the instrument, from which we may conclude that they had not been formed by swinging. Further, the periods of a consecutive series of waves are not constant. For example, one set of east and west tiltings followed each other, with periods measured in seconds of 3·4, 2·0, 2·7, 1·7, 4·1, 3·1, 3·1, 2·7. On another instrument another set of waves, taken at random, followed each other at intervals of 1·9, 2·5, 1.3, and 2·6 seconds. These observations also preclude the idea that the records were obtained by swinging. The most interesting observation, however, is that a pair of conical pendulums, the bobs of which, supposed to be steady points, and which had no pointers for multiplication, gave diagrams about twice as large as similar, but smaller, conical pendulums which carried pointers to multiply any motion relative to their bobs six times.

The actual records are as follows :—

	N.S. Motion. in.	E.W. Motion. in.
Large pendulums with booms 18 inches long...	8	13
Small pendulums with booms and *pointers* 9.5 inches long	4	8

On the assumption that the bobs of these machines had acted as steady points, we should come to the conclusion that the range of north and south motion had been 8 inches, as given by one instrument, whilst it was only ·66 inch as given by another, both instruments being in the same building. It is clear that these two instruments had not behaved as modern seismographs are supposed to behave at the time of an earthquake, but because the displacements indicated are practically proportional to length of boom, or the length of boom and pointers it may be concluded that the instruments had been tilted, and the extent of the displacement measures maximum slopes of earth-waves.

To interpret these measurements, it is necessary to place a level on the stand of the seismograph, and determine by experiment the angular values of tilting corresponding to measured movements of the writing-pointers, the latter quantities varying with the amount of stability given to the horizontal pendulums. Immediately after the earthquake, Mr. F. Omori very kindly made such determinations from a seismograph in the laboratory of the Imperial University, with the result that the maximum slopes which this seismograph had recorded were about one-third of a degree. Waves with such slopes, as shown on the diagram, succeeded each other at intervals of about 2·2 seconds. The vertical motion which was recorded was about 10 mm.; but as ordinary lever spring instruments, when the levers are not parallel to the wave-fronts, are as sensitive to tilting as horizontal bracket or conical pendulum seismographs, these measurements must be regarded as maximum rather than actual values. Combining the maximum wave slopes with these records of vertical motion, we obtain certain values for the lengths of the waves, which may be taken at 18 or 20 feet; and as we know their period, we may determine their velocity of propagation, which appears to have been about 10 feet per second. This is exceedingly slow, but notwithstanding the errors in the observation of vertical motion, I do not think the velocity exceeded double this amount. The velocity of propagation of more truly elastic vibrations will be referred to later.

From these observations, which I think are made for the first time, rather than concluding that modern seismographs are useless whenever vertical motion occurs, we see that on such occasions they must be regarded as angle-measurers. The action of any bracket seismograph when recording horizontal motions depends greatly upon its inertia, but to obtain the best measurements of tilting, any cause likely to produce swinging should be minimised. To obtain a true measurement of vertical motion, the method which first suggests itself

is to have a number of spring lever arrangements in different azimuths, the one which happened to have its arm at right angles to the direction in which the wave advanced being the one which would give the best results.

Independently of any new instruments which may be devised to measure tilting, we now know that the instruments we already possess have a double function, not only measuring horizontal displacements, but also measuring angles of tilting. In order to take advantage of this second function, it is necessary that when a bracket or conical pendulum instrument is once set up, experiments should be made to determine the effects of tilting, otherwise, should it be tilted by an earthquake, its records will not be measurable.

An investigation of considerable importance in connection with the intensity and direction of motion, which has been carried out by Mr. F. Omori, relates to the overturning of bodies of various dimensions. At all temples, which are as thickly distributed as the towns and hamlets, there are stone lanterns, standing on circular or square pedestals, whilst in the vicinity there are hundreds of gravestones, which are square or rectangular in section, and stand freely on their end. Applying the overturning formula to some thousands of these which were overturned in the Nagoya-Gifu Plain, average minima and maxima values for the accelerations experienced at different points within the earthquake area have been determined. Inasmuch as the results given by the formula, which is due to Professor C. D. West, conform with the results obtained by experiment, we have every confidence in the figures given in the following table :—

AVERAGE OVERTURNING ACCELERATION AND MEAN DIRECTION OF SHOCK AS EXPERIENCED AT VARIOUS PLACES IN THE SHAKEN AREA.

CALCULATED BY MR. F. OMORI.

Place, District, and Province.	Intensity in Millimetres per sec. per sec.	Direction.
Tsu, Ano, Ise	<2,000	S. 70° E.-N. 70° W.
Yokkaichi, Miye, Ise	<1,900	S.E.E.-N.W.W.
Kuwana, Kuwana, Ise	2,000	E. 10° N.-W. 10° S.
Tokonabe, Chita, Owari	<2,400	E.-W.
Handa, Chita, Owari	2,000–2,700	S.E.-N.W.
Toyohashi, Atsumi, Mikawa	1,700–1,800	S. 75° E.-N. 75° W.
Okazaki, Nukada, Mikawa	<900	
Atsuta, Aichi, Owari	2,300–3,500	E.N.E.-W.S.W.
Northern part of Nagoya (Toshogoo)	2,600	S. 80° W.-N. 80° E.
North-eastern corner of Nagoya (Kenchiuji)	2,600	S. 60° W.-N. 60° E.
Central part of Nagoya	2,500	
Mean for Nagoya	2,600	S. 65° W.-N. 65° E.
Bamba, Kaito, Owari	>4,100	E.N.E.-W.S.W.
Tsushima, Kaito, Owari		E.-W.
Jimmokuji, Kaito, Owari		E.-W.
Shimo-Otai, Nishi Kasugai, Owari		Nearly N. and S.
Komaki, Higashi-Kasugai, Owari	>4,000	Chiefly E. and W. say W.S.W.-E.N.E.
Iwakura, Niwa, Owari	>4,300	Chiefly N. and S. say S.S.W. N.N.E.
Koöri, Niwa, Owari	>2,100	S.W.-N.E.
Imaichiba, Niwa, Owari	>2,600	
Inaghi, Niwa, Owari	2,300–4,000	S. 15° W.-N. 15° E.
Ichinomiya, Nakajima, Owari.	2,500–3,500	W.N.W.-E.S.E.
Kasamatsu, Haguri, Mino	4,000	W.N.W.-E.S.E.
Gifu, Atsumi, Mino	3,000	W.S.W.-E.N.E.
Ogaki, Ampachi, Mino	3,000	N.N.E.-S.S.W.
Kitagata, Motosu, Mino		Nearly N.-W.
Beppu, Motosu, Mino	>3,900	
Kurono, Katagata, Mino		S. 50° W.-N. 50° E.
Monju, Motosu, Mino		S. 60° W.-N. 60° E.
Kochibara, Motosu, Mino	<1,900	N. 20° W.
Komi, Motosu, Mino	>2,000	S. 60° W.
Higashi-Katabira, Kani, Mino	>2,400	N.-S.
Dota, Kani, Mino	<2,200	S. 20° W.-N. 20° E.
Imawatari, Kani, Mino		N.-S.
Mitake, Kani, Mino	About 1,600	W.N.W.
Takayama, Toki, Mino	>1,800	
Tokiguchi, Toki, Mino	>2,000	N. and S.

Place, District, and Province.	Intensity in Millimetres per sec per sec.	Direction.
Tajimi, Toki, Mino		S.S.W.-N.N.E.
Ikeda-Machiya, Toki, Mino ...		S. 20° W.-N. 20° E.
Utsutsu, Higashi - Kasugai, Owari	2,000	S. 35° W.-N. 35° E.
Akechi, Higashi - Kasugai, Owari	>2,000	
Ono, Ono, Echizen	>1,200	E.-W.
Katsuyama, Ono, Echizen......	About 1,200	Nearly N.-S.
Fujishima, Yoshida, Echizen...	>1,300	Nearly N.-S.
Fukui, Asuwa, Echizen	2,500	N.N.E.-S.S.W.
Asozu, Asuwa, Echizen	<1,100	S, 30° W.
Midochi, Imadate, Echizen ...	About 2,000	
Sabai, Imadate, Echizen	About 1,800	
Takefu, Imadate, Echizen......	About 1,200	N.-S.
Higashiura, Tsuruga, Echizen.	About 1,300	
Tsuruga, Tsuruga, Echizen ...	About 1,200	N.N.W.-S.S.E.
Nagahama, Sakata, Omi	About 2,400	Nearly N.-S.
Hikone, Inukami, Omi	About 2,700	N.N.W.-S.S.E.
Kioto, Yamashiro	<1,200	S.S.W.-N.N.E.
Inari, Kii, Yamashiro...........	About 1,000	N. 10° W.-S. 10° E.
Fukakusa, Kii, Yamashiro......	>1,000	N.-S.
Fushimi, Kii, Yamashiro		S.S.E.-N.N.W.
Nara, Yamato		S.S.W.-N.N.E.
Horiuji, Yamato	About 1,300	S.S.E.-N.N.W.
Osaka, Settsu	About 1,000	

The principal measurements obtainable from the records of seismographs are as follows :—

1. Tokio. Central Meteorological Station.

Maximum horizontal motion, N. and S., about 28 mm. Period, 1.4 sec.

Maximum horizontal motion, E. and W.>about 32 mm. Period, 2.5-4.0 secs.

Maximum vertical motion, 3.1 mm., with period .84 sec., and 4.4 mm. with period 2.3 secs.

2. Tokio. Imperial University.

Maximum horizontal motion, >35 mm. Period, 2.0 sec.
Maximum vertical motion, 9.5 mm. Period, 2.4 sec.

3. Osaka.

Maximum horizontal motion, 30 mm. Period, 1.0 sec.
Maximum vertical motion, 8 mm. Period, 1.0 sec.

4. NAGOYA.

Maximum horizontal motion, > 26 mm. Period, 1.3 sec.
Maximum vertical motion, 6.2 mm. Period, 1.5 sec.

5. GIFU.

Maximum horizontal motion, 18 mm. Period, 2.0 secs.
Maximum vertical motion, > 11.3 mm. Period, 0.9 sec.

At the two latter places the records only showed the first half-dozen vibrations of the disturbance, after which the buildings fell, and the instruments were buried.

At several places in the Neo Valley objects like gateposts have apparently shifted their positions by jumping, each leap being from 1 to 4 feet.

Another observation, also due to Mr. Omori, is that the greater number of columns in one district fell in one direction, whilst those in another district fell in some other direction. Thus, in the southern part of the Nagoya-Gifu Plain, on its eastern side, columns fell towards the west, whilst at towns on the western side of the plain they fell towards the east—an observation which suggests that the movements causing overturning had advanced eastwards and westwards, from a line or tract running north and south down the centre of the plain. In the northern part of the plain the direction of motion, similarly determined, must have been more north and south.

From the measurements of maximum acceleration, and from the records of seismographs which at Nagoya and Gifu gave for the commencement of the disturbance the period of the back and forth motions, we may approximately determine the amplitude and maximum range of motion. The following are a few of such determinations, which it will be observed do not materially differ from the width of fissures found in the open country. The period taken is one and a half second :—

Place.	Acceleration mm. per sec.	Range of Motion.
West of Nagoya	4,500	495 mm. = 19½ inches
Komaki and Kasamatsu	4,000	440 mm. = 17½ inches
Gifu and Ogaki	3,000	330 mm. = 13 inches

It must be remembered that all the numbers given referring to acceleration and range of motion only apply to the open plain, and not to free surfaces like river banks or lines of soft material like river-beds. A phenomenon which seemed to accompany most, if not all, of the Nagoya-Gifu shocks was a hollow, booming sound. These sounds, which accompany all great earthquakes, and even small ones, if they occur in rocky regions, have been discussed at considerable length in the "Transactions of the Seismological Society" (*see* vol. xii. p. 53, and p. 115). They are evidently the result of vibrations conveyed through the earth, and may be continuous with the large vibrations which constitute the earthquake. Professor Tanakadate endeavoured to determine the intervals in time between the sound and the subsequent shakings. Sometimes there was an interval of one or two seconds, whilst at other times the two phenomena were synchronous. The distance of the point of observation from the origin of these disturbances was in all probability at least 10 or 12 miles. While the writer was at Nagoya, which may have been from 25 to 45 miles distant from the earthquake's origin, the sounds never preceded a shaking by more than two seconds. Sometimes they were synchronous, and often there were sounds without any subsequent shaking.

Very many observations were made in Tokio, on the Gifu Plain, and in other places, to determine the velocity of propagation. These have not yet been computed, but the disturbance appears to have reached Tokio at rates of about 8,000 feet per second.

From observations made at the Zikawei Observatory, near Shanghai, which is, roughly, 1,000 miles distant, the velocity with which the movement was transmitted was about 5,104 feet per second. As stated in newspapers, the time taken to reach the Berlin Astronomical Observatory, in round numbers, was forty-nine minutes, the velocity of transmission being about 9,840 feet per second. The disturbance apears also to have been noted at the Magnetical Observatory in Potsdam.

Although numerous experiments and observations have been made to determine the velocity with which motion is conveyed through the earth, we have not as yet any satisfactory explanation of the great differences which have been observed.

From a long series of experiments, extending over several years, which were made in Tokio, where earth disturbances were caused by exploding charges of dynamite, velocities were obtained varying from 200 to 630 feet per second. All these experiments were made in alluvium. Amongst other results the following were of importance:—

1. The velocity of transit decreases as a disturbance radiates.

2. The velocity of transit varies with the intensity of the initial disturbance.

3. The motions transmitted most rapidly are vertical free-surface vibrations; normal motions come next, whilst the lowest records obtained were for transverse motions (*see* "Trans. Seis. Soc.," vol. viii. p. 50, &c.).

Mr. Mallet determined a velocity in sand of 824·915 feet, and in granite, of 1664·576 feet per second. General Abbott, at the destruction of Flood Rock, noted velocities as high as 20,526 feet per second. Professor S. Newcomb and Captain C. Dutton determined velocities for the Charleston earthquake of 17,072 feet per second. The highest velocity for a sound-wave through piano steel of density 7·7 is given by Tomlinson at 5,198 metres (17,049 feet) per second.

Although elastic vibrations may have been transmitted from the earthquake district 150 miles to the Tokio Plain at the rate of several thousand feet per second, the resultant gravity-waves in the Tokio Plain itself do not seem to have been propagated at a greater rate than a few feet per second. With these results before us, all we can say, is, that earthquakes have caused motions in the ground, which apparently have been transmitted at rates varying between 20 feet per second and 20,000 feet per second, the latter being a rate which is

higher than that at which sound waves are propagated through hard steel. Attention has often been called to these facts, but any explanation for them has not yet been formulated.

The result of Professor Tanakadate's magnetic survey shows that there is a slight irregularity in the isomagnetic curves, showing the daily change in declination, which does not appear to have been noticed before the earthquake.

A curious observation, made by Dr. Julius Scriba and other medical men, was that many of the troubles amongst the wounded, like tetanus and erysipelas, were in great measure due to the result of nervous excitement. From my own observations at a time when all were camped in the midst of ruin, and every few minutes a shock was heralded by a booming sound, the only effect that the great catastrophe had produced upon the people was, when they heard one of these unaccountable noises, to cause them to act with unusual quickness in seeking safety. Amongst the Japanese, so far as I could learn, there was no hysteria, fainting, or nervous prostration like that which was observed amongst European women. Although they were surrounded by ruin, the dead, and the dying, all that happened when a hollow thundering announced a coming shock was that they ran quickly for the open, shortly afterwards coming back laughing and talking about the terrible effects of earthquakes. Notwithstanding this, it is not unlikely that this disaster will have produced an impression sufficiently great that for many a year to come it will be commemorated by a religious ceremony, when services will be performed in honour of the dead.

The Nagoya-Gifu Plain is a flat expanse of rich alluvium, covering an area of about 600 square miles. On its east and west sides it is fringed by low hills made out of tertiary tuffs lying at the feet of palæozoic mountains which rise to heights of from 2,000 to 4,000 feet. These latter, which stand up in serrated ridges and overlook the plain, are composed of slates, schists, and other metamorphic rocks. Here and there beds of limestone are found, and rising from the midst of these

hills are several large granite bosses. Volcanic rocks do not exist in this part of Japan. From ancient maps and historical accounts we know that the southern portion of this plain has rapidly been encroaching on the sea. This, no doubt, is largely due to sedimentation; but because evidences of elevation exist at so many places along the eastern coast of Japan, it is reasonable to infer that the growth of land may in part be attributable to this cause. A certain number of earthquakes are every year recorded in the Nagoya Gifu Plain, but it is by no means so often shaken as many other parts of the Empire. A somewhat remarkable observation connected with the seismological history of this portion of Japan is the fact that, although written records of natural phenomena are usually fewer the further we go back in time, yet, from what has been chronicled, great earthquakes were more frequent in the district between Nagoya and Osaka in bygone times than they have been during more recent times. The last severe shakings at and near Gifu took place in 1826, 1827, and in 1859. Many ordinary buildings and even mountains suffered, people and animals were killed, rivers stopped up, and floods occasioned. The shocks lasted for several days. A rather severe shock was felt on May 12, 1889. In 1880 there were shocks and sounds came from the north-west. From 1885 to 1890 the number of shocks annually recorded in that district were respectively 9, 4, 10, 12, 15, and 36. In 1888, in one locality near to the centre of the late disturbance, 19 shocks were recorded; in 1889 the number was 15; in 1890 there were 20 shocks; and between January and October 1891, that is, up to the time of the great disturbance, 26 shocks were noted. These figures suggest the idea that for four years before the Great Earthquake there was a marked increase in seismic activity, and that an unusual number of small disturbances had heralded the great collapse.

Even if it is only sometimes true that small shakings warn us of larger ones to follow, because the latter are so terrible in

their effects, it would seem well to carefully study districts in which from time to time there are definite indications of an increase in underground activity.

Earthquakes generally occur in mountainous countries where the mountains are geologically young, or in countries where there is evidence of slow secular movements like elevation. These latter movements are usually well marked in volcanic countries, and it is not unlikely that the majority of earthquakes, even in volcanic countries, are the result of the sudden yielding of rocky masses which have been bent until they have reached a limit of elasticity. The after-shocks are suggestive of the setting of disjointed strata.

In Japan, the majority of the earthquakes which we experience do not come from the volcanoes, nor do they seem to have any direct connection with them. Assuming that the greater number of earthquakes represent interruptions in the general process of rock crumpling, it would appear that light might be thrown upon the time of their occurrence by careful observation on the change of level in a district where seimic disturbances were frequent. To accomplish this it is suggested that several miles of water-pipes be laid at right angles to a known axis of elevation, and that continuous photographic record be kept showing the height of the water in standards at each end of the line. A more complete arrangement would be to have two lines of piping, placed at right angles. The cost of the installation would be about 500*l.* or 3,500 *yen*.

Possibly self recording tromometers such as are described in this number might at much less expense throw light upon the questions relating to change of level. Arrangements for these investigations are now being made.

In conclusion, it must not be overlooked that these remarks on the Great Earthquake only aim at giving an outline of phenomena which have been observed, and the general character of the results to which they lead. The complete account

of this great disaster to be issued under the auspices of the Imperial University of Japan will not be ready for publication for several months.